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**A longitudinal analysis of performance, growth and maturation in
youth rugby league players: implications for talent identification and
development**


**Thesis submitted in accordance with the requirements of the University of Chester for
the degree of Doctor of Philosophy**

By Mark Waldron

Declaration of Originality

This work is original and has not been previously submitted in support of a Degree, qualification or other course.

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Date11/06/13.....

Publications based on the thesis

Waldron, M., Worsfold, P., Twist, C. & Lamb, K. (2011). Concurrent validity and test re-test reliability of a Global Positioning System (GPS) and timing gates to assess sprint performance variables. *Journal of Sports Sciences*, 29, 1613-1619.

Waldron, M., Worsfold, P., Twist, C. & Lamb, K. (2011). Predicting 30 m timing gate speed from a 5 Hz Global Positioning System (GPS) device. *International Journal of Performance Analysis in Sport*, 11, 575-582.

Waldron, M., Worsfold, P., Twist, C. & Lamb, K. (2012). The reliability of tests for sport-specific motor skill amongst elite youth rugby league players. *European Journal of Sport Sciences*. DOI:10.1080/17461391.2012.714405

Waldron, M. Twist, C., Worsfold, P. & Lamb, K. (2011). Movement, physiological and technical demands of elite youth rugby league and the relationship to closed performance and anthropometry. *Proceedings from British Association of Sports & Exercise Sciences Annual Conference 2011, 6-8th September (University of Essex)*.

Waldron, M. Twist, C., Worsfold, P. & Lamb, K. (2011). A longitudinal assessment of growth and performance in selected and unselected youth rugby league players. *Proceedings from European Congress of Sports Sciences Annual Conference 2012, 4th-7th July (Vrije Universiteit Brussel)*.

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Abstract

This study monitored a cohort of youth rugby league players from one professional club in England, across three competitive seasons (under-15 to under-17 age group). The aims were to establish which dimensions of growth and performance characterized players who were either coach-selected or unselected each season and to evaluate annual developments in growth and performance. It was also necessary to establish the credibility of various measurement techniques that are implicated in the talent identification process. In the assessment of sprint performance, GPS measurements systematically underestimated both distance and timing gate speed but can be used to reliably evaluate sprint performance, particularly for measurements of peak speed (95% Limits of Agreement (LoA) = 0.00 ± 0.8 km·h⁻¹; CV = 0.78%). Using a larger sample of youth team sport players ($n = 60$), multiple linear regression analysis, incorporating mean and peak GPS speeds as predictors of timing gate speed, yielded a prediction model that was able to provide a valid alternative to timing gates in the assessment of sprint performance over 30 m. With regards to the reliability of assessments of sport-specific skill in youth rugby league players, no comparisons met the pre-determined analytical goal of ‘perfect agreement’, meaning that up to 56% of players’ skill could be misinterpreted. The credibility of such assessments should be questioned and alternative tests considered. In the period between the under-15 and under-16 group, there were large annual increments in speed (5.02 Δ%), force (13.82 Δ%) and power (19.85 Δ%) generated over 10 m sprint intervals and predicted vertical jumping power (13.02 Δ%), with concomitant developments in body mass (5.14 Δ%), lean body mass (3.20 Δ%) and predicted muscle of the quadriceps (10.12 Δ%). A discriminant function analysis also highlighted 30 m force and 10 m acceleration as significant predictors of selected players in the under-15 group and under-16 group, explaining 47.3% and 40.7% of the between-group variance, respectively – which was the case independent of age at peak maturity. However, there were

no differences between selected and unselected players in the under-17 group. During match time, there were differences between selected (57.1 ± 11.9 min) and unselected (44.1 ± 12.3 min) players for average playing interval in the under-16 group. In turn, selected players covered more total distance (5181.0 ± 1063.5 m c.f. 3942.6 ± 1108.6 m, respectively; $P = 0.012$) and high intensity distance (1808.8 ± 369.3 m c.f. 1380.5 ± 367.7 m, respectively; $P = 0.011$) than unselected players. When age at peak height velocity (PHV) was statistically controlled, only distance in zone 3 and summated-HR remained higher in the selected players of the under-16 group. Conversely, higher values amongst the unselected under-16 players for total and relative distance in zone 4, 5 and high intensity were revealed. There was a relationship in the under-15 group ($R = 0.702$, $P < 0.001$), under-16 group ($R = 0.607$, $P < 0.001$) and under-17 group ($R = 0.671$, $P < 0.006$) between the number of successful ball carries and 10 m sprinting force, thus supporting the use of 10 m sprinting force as a predictor of match performance. The relationship ($r = 0.51$, $P = 0.044$) between aerobic capacity and $\text{HIT} \cdot \text{min}^{-1}$ in the under-17 group also provides preliminary evidence of aerobic endurance as a potential predictor of match running intensity. It was concluded that players who are coach-selected are not characterized by match related performance variables but are offered greater match exposure during the under-16 age group, resulting in larger running distances. Unselected players are unrewarded for higher intensity running during matches when maturational age is statistically controlled and are also equally effective in regard to tackling and ball carrying outcomes. These results collectively indicate the inability of match performance measurements to contribute to talent identification processes in players of this type. The changes in growth and performance should be used to guide talent development practices of rugby league coaches. In particular, the assessment of force (i.e. the product of acceleration and body mass) should be considered as an important factor in differentiating between higher and lower ability players, as well as relating to match performance.

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Chapter 1: Introduction

1.1 Current evidence and limitations of talent identification in rugby league

Identifying young athletes with the potential to perform at the elite level remains a challenge for practitioners involved in team sport (Vaeyens et al., 2009; 2008). In order to inform the search for ‘talented’ young players, there is an increasing need for scientific intervention in talent identification programmes (Vaeyens et al., 2008). Engaging with such processes may limit the reliance upon subjective, and often uninformed, dogmatic identification procedures that characterize current practice, particularly in team sports such as rugby league (Till et al., 2010).

Talent in team sport is regarded as a common-sense explanation of high ability (Helsen et al., 1998a) which is often subjectively identified by coaches and talent scouts employed by individual sports clubs (Vaeyens et al., 2008). Talent in team sports may be expressed in a variety of ways and can be strongly associated with superior physical abilities, such as speed, skill and aerobic endurance, each of which are an inherent part of team sport performance (Vaeyens et al., 2008). Various anthropometric measurements and maturity assessments are also commonly utilised to differentiate between team-sports players of higher and lower ability and may account for performance improvements as a function of chronological age (Mendez-Villaneauva et al., 2011; Le Gall et al., 2010). The ability to recognize which measurements of performance and anthropometry best associate with players of higher ability can help to prioritize training practices for rugby league practitioners and may contribute to the identification of talented players.

In youth rugby league, research has identified various dimensions of anthropometry and performance that distinguish ‘higher ability’ (national) and ‘lower ability’ (regional) players (Till et al., 2011). A combination of skinfold thickness, sprinting speed (10 m to 60 m) and endurance capacity explain approximately ~28% of the variance in selection for national squads between the ages of 13 to 15 years (Till et al., 2011). However, there are various novel measurements of performance, such as ‘sprint momentum’ (Baker & Newton, 2008), that have not been considered for use in the identification of youth rugby league players. Introducing similar tests (amongst others) may be beneficial for the talent identification process since it has been shown to differentiate between lower and higher division adult rugby league players (Baker & Newton, 2008). Furthermore, little attention has been afforded to players of later adolescence (15 to 18 years), where the influence of maturity and opportunity to develop is reduced. Whilst Australian-based studies have evaluated similar performance characteristics (i.e. speed, endurance) of youth players who are either selected or unselected to play for elite squads during later adolescence, the effect of maturity on these variables has not been considered (Gabbett, 2009; Gabbett, 2005). This is surprising since it has been shown that young soccer players of advanced maturity (biological age) can sprint faster and jump higher than their later maturing peers (Malina et al., 2004). Consequently, it is advocated that maturational age should be statistically controlled for when comparing groups of higher and lower ability players (Vaeyens et al., 2006).

A notable limitation of previous studies attempting to differentiate between players of higher and lower ability is the failure to adopt longitudinal research designs, which has limited the understanding of the rate at which such variables are acquired by potentially talented individuals over time. Indeed, studies in rugby league incorrectly claim to have identified Annual data plots for performance using cross-sectional research designs (Till et al., 2011;

Gabbett, 2002). Whilst one should expect age and maturity-related growth and performance developments amongst team sport players (Philippaerts et al., 2006), the time-course and magnitude of those factors identified as important to rugby league players has yet to be established. Evidence of longitudinal changes in growth and performance are currently restricted to other team sports, such as soccer (Philippaerts et al., 2006), leaving no evidence of the typical developments in elite young rugby league players. Such information would supplement current talent development processes, informing practitioners of the expected performance increases across annual age groups. A potential problem with performing longitudinal research in an applied sports science context, is the threat of ‘sample mortality’, particularly if a large, normative sample is required. However, a larger sample of players from different clubs may also be difficult to study given the wide-spread locations of each club and the number of research staff required. Therefore, notwithstanding the smaller sample sizes associated with case-study research designs, such an approach may partly counter the above problems.

In addition to closed testing procedures, talent in sport has been defined as “someone who *performs* better than his or her peers *during competition* and who has the potential to reach the elite level” (Elferink-Gemser et al., 2004, pg. 1053, emphases added). In practice, the identification of young talented rugby league players, as well as other team sports, is often based upon captions of match performance (Till et al., 2010; Vrljic & Mallet, 2008). Given the development of portable movement analysis devices (Global Positioning Systems), physiological monitoring equipment and performance analysis techniques, it is possible to evaluate match-related markers of performance, such as game-specific skills, running intensity and physiological load (see McLellan et al., 2011, 2010; Waldron et al., 2011a; Sykes et al., 2009, 2010). Such approaches can develop upon current talent identification

methods in favour of ecologically valid measures of competitive performance and, importantly, could serve to validate the use of closed performance tests for identification purposes (Vaeyens et al., 2009; Falk et al., 2004). Given the paucity of match-related research in youth rugby league, such information would also enable practitioners to facilitate young players with the appropriate training stimulus, thus enhancing talent development practices.

1.2 Thesis structure

The thesis adopted a longitudinal research design, whereby a cohort of youth rugby league players, sampled from one professional club in the North West of England, were monitored over a three season period. The sport of rugby league represents a popular team sport in the North of England and is engaged in regional and national talent development programmes under the co-ordination of the Rugby Football League (RFL). The selected club that chose to participate in this study was also required to identify and develop players for participation at the club level, leading to the ‘selecting’ or ‘unselecting’ of players at each annual age group. As such, the club was interested in understanding the factors that underpin talented performance. The process spanned between February 2010 and June 2012, beginning with the under-15 age group and finishing with the under-17 age group, thus enabling continual monitoring of players’ progress through later adolescence towards the transition to professional status. The aim was to establish which selected dimensions of growth and performance characterized players who were either coach-selected or unselected at the conclusion of each season. Importantly, the coaches at the club did not have structured criteria for the identification of players. Rather, players were selected based on the subjective assessments of the selectors. As such, based on the methods of previous studies, this study aimed to assess selected physical performance and attributes of players that were selected or

unselected each season, irrespective of the decision-making process of the coaches. It is important to consider that the variables measured herein only partially represent the attributes that relate to talented performance in rugby league and did not entirely address the multifaceted nature of talent. A secondary aim was to evaluate the annual developments in such variables using a sub-section of the sample that was able to complete each season of the study.

The identification of higher ability requires the valid and reliable administration of performance tests. For example, tests of tackling and catching technique in rugby league are reported to differentiate between players of higher and lower ability (Gabbett et al., 2007). However, the credibility of such tests (amongst others) is yet to be established for application to the talent identification and development process. This is of greater significance when adopting novel approaches to the assessment of physical performance, such as tests for sprinting force and power or sport-specific skill, since their capacity to recognize small, yet potentially important, differences in performance is not established. Therefore, prior to the start of each longitudinal study, a preliminary series of studies were undertaken. These studies aimed to assess the validity and reliability of certain key performance parameters, such as sprint performance and sport-specific skills that are often implicated in the talent identification process in rugby league.

1.3 Aims of the thesis

The specific aims of the thesis were to;

- 1) Establish the reliability and validity of 5 Hz Global Positioning Systems (GPS) for quantification of sprinting ability in youth rugby league players, with special reference to linear sprinting speed and acceleration in youth participants.
- 2) Examine whether regression analysis could yield an accurate model to predict over-ground speed from GPS values.
- 3) Establish the reliability of tests for sport-specific skill in youth rugby league players.
- 4) Monitor changes in annually collected anthropometric and closed performance data of groups of youth rugby league players that were successful in progressing through successive age groups during later adolescence (under-15 to under-18 age groups).
- 5) To establish the anthropometric and performance factors that differentiate between selected and unselected youth rugby league players (under-15 to under-18 age groups).
- 6) Evaluate the relationship between anthropometry, physical performance and match performance in youth rugby league players (under-15 to under-18 age groups).

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1.4 Organization of the thesis

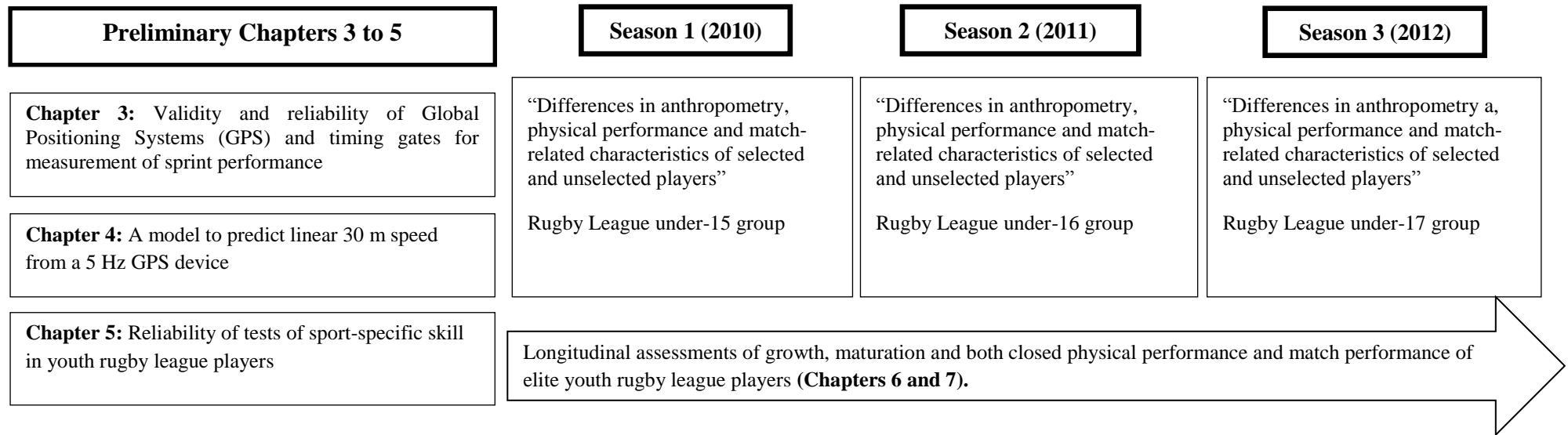


Figure 1.1. Chronological organisation of the current thesis

The thesis was structured to allow a period of preliminary data collection at the beginning of the project, culminating in Chapters 3 to 5. Two concurrent longitudinal studies were subsequently undertaken, with the first focussing on the assessment of growth, changes in maturity and performance in a closed environment and the second evaluating performance during match time and its relationship to anthropometry and closed performance. The chronological structure is outlined in Figure 1.4.

1.5 Order of empirical studies

Chapter 3 - Concurrent validity and test re-test reliability of a Global Positioning System (GPS) and timing gates to assess sprint performance variables

Chapter 4 - Predicting 30 m timing gate speed from a 5 Hz Global Positioning System (GPS) device

Chapter 5 - The reliability of selected tests of sport-specific motor skill in youth rugby league and soccer players

Chapter 6 - A longitudinal analysis of growth, maturation and physical performance in selected and unselected youth rugby league players

Chapter 7 - A longitudinal analysis of match performance in selected and unselected youth rugby league players and the relationship to growth and physical tests of performance.

Chapter 2: Review of Literature

2.1 The development of objective talent identification systems in sport

The early identification of young talented individuals has become increasingly important across many performance domains (Abbott et al., 2005). From a sporting perspective, talent identification has emerged as a primary concern for most sporting institutions and professional bodies (Wolstencroft, 2002), particularly within popular team sports such as soccer and rugby league, where players are often perceived as ‘valuable commodities’ (Lonsdale, 2004). Modern-day team sport has also experienced an influx of foreign investment, subsequently leading to financial disparities between competing clubs. Therefore, obtaining players worthy of raising spectatorship without incurring great financial decrement has become an implicit requirement of the modern-day club (Lucifora & Simmons, 2003). As such, an increased focus has been placed upon detecting, identifying and developing localized talent (Williams & Reilly, 2000).

In order to inform the search for ‘talented’ young players, there is a growing need for scientific intervention within fundamental talent identification processes (Vaeyens et al., 2008). Realising such a prospect may limit the reliance upon subjective, and often uninformed, dogmatic identification procedures that characterize many current talent identification practices (Vaeyens et al., 2008; Wolstencroft, 2002). Furthermore, in the context of team sports, the inability to identify and process youth talent from localized grass-roots level to the elite arena is often perceived to be the principal reason for the lack of success at international competitions (Winkler, 2001). Indeed, such issues are not unique to team sport and appear to be a concern for many Olympic sports (Bullock et al., 2009;

Davidson, 2006), leading to the generation of various talent search initiatives, such as the ‘UK High Performance Talent Programme’ or the Australian National Talent Identification and Development Programme’ (NTIDP) (Vaeyens et al., 2009).

Many sporting institutions (e.g. Australian Institute of Sport or ASPIRE in Qatar) have initiated talent search programmes, principally aimed at recognizing talent during various stages of maturation, thereby identifying young athletes who have the highest likelihood of future success (Pearson et al., 2006). Talent identification is described as, “the process of recognizing a current participant with the potential to excel in a particular sport” (Vaeyens et al., 2008, p. 703). By identifying young athletes early, the correct developmental procedures can be implemented sooner, which may facilitate the realisation of their potential (Vaeyens et al., 2008). This latter process is referred to as talent development (talent development). The correct implementation of talent identification and talent development programmes have clear benefits for elite sporting bodies and many professional clubs since they may also qualify the financial outlay incurred whilst pursuing the initial recognition of youth talent. Indeed, a causal relationship between financial outlay by the Australian government in developing young sporting talent and the Olympic medal return was demonstrated by Hogan and Norton (2000), reflecting an investment of approximately A\$8 million per medal won at the previous Olympic games.

The Australian Institute of Sport (AIS) talent search programme, which was initiated in reaction to Australia’s poor performance in the 1976 Olympics, was famously implemented as an objective, science-based approach to talent detection. This programme pro-actively matched young athletes with ‘appropriate’ sports, based upon multi-dimensional factors

(Burgess, 2007; Wolstencroft, 2002). Such an approach was aimed at reducing the traditional coincidental meeting of a performer with a given sport, which is largely influenced by geographical and environmental factors (Burgess, 2007). The AIS talent search programme provided an original example of a ‘primary detection system’ which can be referred to as ‘scientific selection’ (Wolstencroft, 2002), meaning that the sport was introduced to the athlete, rather than ‘*identification*’ or ‘natural selection’ where the athlete is recognized whilst already participating within the sport (Wolstencroft, 2002; Williams & Reilly, 2000). Subsequent research has shown how such detection processes may be useful in finding athletes with the generic ability to compete at an elite standard. For example, Bullock et al. (2009) selected potentially talented ‘skeleton’ athletes based upon 30 m sprint time, and developed these athletes to Olympic standard within 14 months, via a ‘deliberate programming’ approach. Within such programmes, objective multi-dimensional measurements (such as physiological, psychological and anthropometric) are profiled over varying time periods and are perceived to be ‘talented’ performance dimensions by most Olympic Development Programmes (Pearson et al., 2006; Hoare & Warr, 2000). The ostensible success of such initiatives has also been well recognized by the British government (DCMS, 2002) and favourably documented by leading academics (Bloomfield, 2003). While such approaches appear useful for sports that are under-populated and lacking in the depth of competition (Baker, 2003; Hoare, 1998), in more popular multi-national sports such as rugby league, the process of identifying athletes that are already participating in the sport is often preferable.

Although the talent search programme of the AIS offers the most recent mainstream example of talent detection, the history of Olympic sport in many Eastern European countries provides further indications that quantifiable talent detection is not an entirely contemporary concept

(Pearson et al., 2006). For example, it is claimed that 80% of Bulgarian medallists in the 1976 Olympic Games were the direct result of a thorough detection and/or talent identification process, underpinned by scientific evidence, such as strength and flexibility measures (Bompa, 1999). Romanian and East German athletes in the 1972, 1976 and 1980 Olympics, also selected via scientific processes adopted in the late 1960s, are further examples of early talent identification systems (Bompa, 1994). Riecken et al. (1993), reporting on previous talent identification programmes from East Germany and the former Soviet Union, documented talent identification processes with children from the age of six to eight years based upon current performance and proficiency in sport-specific motor skills. Such procedures are typical features of previous talent identification models and were justified on the basis that coaches were enabled to expose potentially talented performers to a higher training stimulus for a longer time period (Gullich & Emrich, 2006). For Romania and many other Eastern European countries, the long-term use of scientific talent detection was an implicit part of the amalgamated sport and education culture, which filtered into Western Europe in later years (Metsä-Tokila, 2002). Of course, some differences within the “Western” approach to talent identification were apparent, namely the early freedom of choice with regard to sports participation at younger ages; a factor that is inherent within many talent development models and characterizes the first (sampling years) of a three-stage elite performance process (sampling - specialization - investment) currently advocated (Cote et al., 2007). However, whilst certain variations on this theme are evident, a global approach to talent identification appears to have evolved, encompassing the necessity for scientific intervention and regular performance profiling. Such an approach has been utilised regularly due to its objectivity at earlier stages of talent development, ostensibly providing practitioners with a time and cost effective method with which to support an athlete’s development (Vaeyens et al., 2009). However, the available information regarding the actual procedures

used to identify talent within these early talent identification attempts are, unfortunately, lacking in detail. Nonetheless, it remains clear that talent identification may be approached using laboratory and/or field-based assessments of current athletic status that are apparently representative of sport-specific performance characteristics or profiles.

2.2 Defining the concept of talent

Current concepts of ‘talent’ often refer to the recognition of a child’s future potential to perform at a standard superior to others (Vaeyens et al., 2008; Regnier et al., 1993). This superior ability appears to be both genetically (Pearson, et al., 2006; Miah & Rich, 2006; Helsen et al., 2000) and environmentally determined (Philips et al., 2010; Howe et al., 1998; Bloom, 1985), but the notion of what constitutes a talented sports person is far from universally agreed. For instance, the measurement of ‘future potential’ remains variable given the range of environmental influences that may prevent a young performer from accessing the correct developmental processes during maturation (Pearson et al., 2006). Moreover, as performances at younger ages can fluctuate considerably, the precision with which talent can be identified has to be questioned (Howe et al., 1998). Problems of identification, therefore, appear to stem from the lack of a global opinion on what constitutes talent (Abbott & Collins, 2004; Morris, 2000).

Talent may be broadly referred to as “general sport ability” (Lidor et al., 2005, p.318) in a young person and is often measured using multiple facets that underpin potential performance in sport, such as physical, mental and social traits (Lidor et al., 2005; Elliot et al., 1990). Indeed, as discussed previously, adopting multi-dimensional measures of performance has

recently emerged as the predominant method of talent identification and invariably includes a variety of performance tests designed to assess physiological, psychological, anthropometric and sport-specific motor skill proficiency during the maturational period (Williams & Reilly, 2000). However, talent has also been suggested to be “an appealing and common sense explanation that underlies skill in sport” (Helsen et al., 2000, p.728) which may not be clearly and objectively recognized. Certainly, talent manifests in diverse ways amongst team sport players (playing in a variety of strategic positions) that differ from continuous, individual sports such as running or cycling (Mirkov et al., 2010). For example, as will be reviewed in following sections, rugby league players possess a variety of different physical, physiological and motor-skill abilities, which appear to underpin their selection on to talent development programmes (Till et al., 2011). However, talent may be realised by simply out-performing the nearest competitive counterpart (Ericsson, 2003), which is only clearly recognized by the comparison of players performing in a shared context (i.e. the same team or match scenario).

Within team sports, talent identification is typically reliant solely upon the ability of the coach to understand what constitutes a ‘higher ability’ player (Vaeyens et al., 2006; Lidor et al., 2004; Reilly et al., 2000a). Perhaps logically in team sports, talent identification continues to be a practice particular to each professional club, with little academic evidence to ratify the processes that underpin the devised talent identification programmes and a clear lack of successful implementation (Vaeyens et al., 2008; Durand-Bush & Salmela, 2001). However, it should be recognized that tacit coaching knowledge may offer information beyond that captured by scientific measures (Lidor et al., 2009). In a study by Vrljic and Mallet (2008) investigating the opinion-based practice of soccer coaches (using a semi-structured interviewing process) insight was gained into the criteria the coaches adopted whilst identifying talented youth players. Their findings highlighted that the elite sports coaches

predominantly regard talent to manifest in match performance, basing many assumptions of talent upon 'real-world' characteristics, such as dribbling skill and spatial game awareness. In a further study, soccer coaches have also suggested that their appraisal of athletes is based upon the movement patterns performed by players during match time (Christensen, 2009). Given the development of various motion analysis techniques in the current day, such facets of performance may now be measurable. This evidence reinforces that the definition of talent, for some coaches, may be immeasurable in closed contexts, since tests conducted in closed environments lack the ecological validity required to appropriately represent the competitive environment. Other authors have also suggested that most team sports coaches (anecdotally) will claim to be able to visually identify talent (Helsen et al., 2000). This is unsurprising given that it is not uncommon for professional sports clubs to select players based upon single captions of performance in competitive environments, often referred to as 'trials' (Starkes et al., 1996). Indeed, the Rugby Football League (RFL) openly adopt such an approach, selecting players for regional talent development camps on the basis of 'performance' within competitive matches organized between local service area squads (Till et al., 2010).

What appears clear from the sparse evidence available is that talent in sport is characterized by many separate facets, which are linked to performance in either or both simulated and real-world settings. It is the relationship between these factors and the stability of each in identifying talented players which remains less well defined. Furthermore, some authors contend that talent identification research requires information derived from both subjective and objective practices, rather than the adoption of one particular approach (Reilly et al., 2000b; Falk et al., 2004; Lidor et al., 2009; Waldron & Worsfold, 2010). Therefore, it is prudent to gather further knowledge relating to the 'hidden' criteria upon which coaches base

their decisions. That is, retrospectively profiling the progress in performance of both selected (identified) and unselected players, as decided by the coaches/selectors. Whilst such underlying criteria may be transient in nature owing to the evolving requirements of team sport (rugby league), training players to perform well in factors most associated with success may enhance general player development. Indeed, understanding the relationship between physical ability, such as sprinting capacity, and match-related performance may also identify the most important trainable fitness components.

2.3 Chronological and biological maturation

Typically characterized by cross-sectional designs, previous research has attempted to profile various multi-dimensional characteristics, such as physiological, anthropometrical, psychological and game-specific skills in order to predict later success in adult competition (Reilly et al., 2000). These approaches have been criticised since many changes occur in youth performance due to the maturation process (Williams & Reilly, 2000; Pearson et al., 2006). Moreover, these changes will often vary between individuals. A plethora of research is currently available evidencing the theoretical application of the so called ‘relative age effect’ (RAE). For example, a study by Helsen et al. (1998a) selected 1,200 birth dates of three groups of soccer players in Belgium; professional players performing in the top division from 1993 to 1996, youth players aged 10 years who were selected for national youth teams between 1989 and 1995, and youth players (< 16 years) transferred in 1995 to a top division youth team by an official youth transfer ($n = 485$). Helsen et al. demonstrated that youth players born between the opening phase of the selection period (August to October), beginning in the 6-8 year age group, were the most likely to be identified as talented and

often exposed to higher amounts of coaching. Eventually, these players were the most likely to play elite standard soccer, defined by international and professional experience.

Such findings have been supported by a large body of research in youth football which has demonstrated that advanced biological maturity may be associated with a multitude of physical and cognitive benefits during adolescent stages of development in a range of team-based sports, resulting in earlier, preferential selection for talent development programmes (Malina, 1994; Brewer et al., 1992; Simmons & Paul, 2001; Vaeyens et al., 2005; Helsen et al., 2005; Vincent et al., 2008; Mujika et al., 2009; Costa et al., 2010; Guttierrez, et al., 2010; Till et al., 2010). Therefore, these findings indicate that the academic year group segregation of August to September places athletes who are relatively older (chronologically) in a favourable position for selection onto talent development programmes (Brewer et al., 1992). It is suggested that advanced physical development of the relatively older players is advantageous to gain selection, whereas younger players may be overlooked due to a decreased likelihood of biological maturity and subsequent physical development (see section 2.5 for further details on physical maturation). Furthermore, RAEs have been reported to exist predominantly within soccer (Costa et al. 2010; Guttierrez et al., 2010; Mujika et al., 2009) and, more recently, rugby league (Till et al., 2010). Research has also documented the increased likelihood of RAEs in the under-15 to -18 age groups, particularly within popular team sports, perhaps owing to a critical accumulation of training and subsequent development within this period (Cobley et al., 2009). However, in rugby league, current evidence suggests the presence of RAEs in the lower levels of the amateur community game through to elite senior Super League players (Till et al., 2010). Interestingly, playing position appeared to act as a moderator of RAE, whereby more of the players from the 'outside back' (24%) and

‘half-back’ (19%) positions were born in the (later) third and fourth quartiles, compared to ‘forwards’ (17%) and ‘second-row’(4%) positions.

While RAEs influence physical maturity and related performance measures in the majority of studies, the presence of RAEs in handball without the accompanying physical and cognitive benefits has been reported (Schorer et al., 2009). Furthermore, Baker and Logan (2007) showed that relatively younger ice hockey players received a higher selection value during the drafting process, thus highlighting that the RAE concept may be less prominent in certain sporting contexts. Consistent with the ‘compensation phenomenon’ (Williams & Ericsson, 2005), relatively younger players may be compelled to adopt various strategies in order to cope with the demands of direct competition alongside physically advanced players. This may be more noticeable in sports that exhibit physical bias at younger ages, such as rugby league (Till et al., 2010). Moreover, the ‘10 years (~ 10,000 hours) of practice’ rule purported to be required to develop expertise through deliberate practice has been challenged as an over-estimate and unnecessary for all participants (Bullock et al., 2009; Helsen et al., 1998b). However, what remains unknown from the data presented by Schorer and colleagues (2009) is the years of accumulated playing experience, regardless of relative age. For example, poor participation rates, low-level coaching, and geographically limited talent development areas in rugby league (Webb & Rotherham, 2011), mean potentially talented players will have restricted playing experience regardless of their physical maturity. Indeed, years of competitive experience, defined as exposure to match-like scenarios, are often reported in studies addressing differences between ability levels in youth team sport (Gabbett, 2007; 2002; 2000; Malina et al., 2007). Such an issue should be noted by all concerned with the investigation of RAE, particularly if assuming that coaching experience underpins the superior ability of chronologically advanced athletes.

In the current literature, little attention has been afforded towards the later years of development (i.e. 14 – 18). This period reflects the stage in which the transition from youth to adult performance must be managed (Le Gall et al., 2010). Current periodization models refer to this stage as the ‘specialization’ tier (Cote et al., 2007) or the ‘learning to compete’ or ‘learning to win’ stage (Balyi & Hamilton, 2004). This matter is particularly important within team sports given that a later period of deliberate practice and structured scientific support will occur. More generally, all team sports are regarded as late specialization sports, defined by the point at which peak performance is required to occur (Balyi & Hamilton, 2004). While it is reasonable to suggest that a delay in rugby league expertise will occur given that players are not contracted to professional clubs until the under-15 age group, little evidence exists regarding the prevalence of late development to expertise in rugby league.

2.4 Longitudinal models of talent identification and talent development

Understanding how various physical performance assets change over time is central to the talent identification and development processes. Applying talent identification processes that disregard the developmental nature of potential talent and attempt to identify the individuals in a static manner are largely criticised (see Vaeyens et al., 2009). Therefore, any ‘one-off’ caption of performance or quantifiable laboratory-based measures of ability, are inevitably variable during growth and are incapable of solely identifying talent (Lidor et al., 2009). In order to negate this factor, some authors have sought to differentiate between current performance and potential performance (Vaeyens et al., 2009; 2008; Wolstencroft, 2002). The ultimate goal of any talent identification and/or talent development process is to produce sports people capable of meeting the demands that characterize sport at the elite adult level

(Pearson et al., 2006). However, sampling the current performance of a junior soccer player, for example, is problematic since evidence suggests that the relationship between quantifiable performance during adolescence and adulthood is non-linear (Huijgen et al., 2009; Malina et al., 2005). The assumption that performance at a young age will translate into performance in an adult setting is often not borne out (Morris, 2000). For example, only 44% of athletes in the 2004 Olympics made their international debut as a junior (Gullich, 2007), supporting the finding more than 20 years earlier by Bloom (1985) of a poor correlation between junior and senior success. Such evidence clearly indicates the potential for variance in the factors that predict success during different maturational stages and the probability that potentially talented players are unrecognized. This is particularly noteworthy in team-based sports given the stochastic nature of performance and the resultant variability of demands imposed on players, even in the adult setting (Bangsbo, 1994; Rampinini et al., 2007). Moreover, it is certain that maturation has an impact upon development and precludes clear identification of talent at earlier stages of participation (Pearson et al., 2006). Longitudinal analyses may help to overcome such issues as they can provide a retrospective interpretation of what to expect from players who succeed at certain age groups and maturational stages. Such research designs may also reveal the time-course of factors that contribute to selection across year groups and establish the relative importance of measurable indicators over the developing years.

2.5 Physiological basis of maturation and exposure to sport and exercise

The maturation process has many important implications for talent identification in sport. Indeed, the rate at which biological maturity occurs profoundly influences the performance in physical tests by young athletes (Philippaerts et al., 2006; Malina, 2004). A typical growth

curve over the course of a human life-span undergoes two principal acceleration periods, with the latter pubertal growth stage (gonadarche) occurring during adolescence (Sherwood, 2009).

During gonadarche, hypothalamic activity provides the stimulus for growth and is associated with a cascade of hormonal productions, beginning with an increase in the delivery of hypophysiotrophic hormones (such as gonadotrophic-releasing hormone; GRH) through the hypothalamic-pituitary venous portal system (Widmaier et al., 2011). A subsequent rise in the release of growth hormone (GH), follicle stimulating hormone (FSH) and leutinising hormone (LH) from the anterior pituitary gland into the systemic blood stream is induced (Widmaier et al., 2011). Puberty occurs, typically, between the ages of 13-18 in boys, characterized by an observable, rapid linear growth curve (Rexhepi & Brestovci, 2010; Sherwood, 2009; Jolicoeur et al 1988; Tanner et al., 1966). The inflated appearance of GH and other hormones derived from the anterior pituitary, provide a mediating mechanism for various endocrinal glands situated about the body. For example, GH released into the blood stream will induce an increase in the growth stimulating insulin-like growth factor I (IGF-I) from the liver, promoting the retention of nitrogen, causing anabolism and concomitant protein synthesis (Malina et al., 2004). The production of FSH and, to a lesser effect in males, LH, provides a stimulus to the gonads (male testes), where an influx in the production of testosterone and associated androgens such as dihydrotestosterone can be observed (Widmaier et al., 2011). The accelerated production of androgens (known as sex steroids) during gonadarche also promotes nitrogen retention and may aid in the regulation of metabolic responses to exercise in children (Mauras et al., 2007). Such hormonal changes during adolescence have been noted within short longitudinal studies amongst junior soccer players, demonstrating a significant rise in serum testosterone over six month intervals and

parallel increases in stature, body mass and testicular volume (Hansen et al., 1999b). Interestingly, players of superior (elite) ability were shown to have a higher concentration of serum testosterone and were taller and heavier than their sub-elite counterparts (Hansen et al., 1999b).

Such endocrinal changes also induce developments in bone ossification patterns and promote further protein retention which, in turn, facilitates the structuring of bone matrix and the deposition of calcium and phosphorus (Martha et al., 1992). Whilst an increase in testosterone mediates the latter growth spurt in adolescents, such androgens may also work synergistically with GH to promote the development of bone length and thickness, develop structural proteins for growth of connective tissue muscle (Boisseau & Delemarche, 2000) and, in conjunction with estrogen, provide a feedback mechanism to the hypothalamus to facilitate the continued production of GH (Boisseau & Delemarche, 2000; Mauras, et al., 1995). Alterations in muscle and bone morphology during pubertal stages impact upon a child's capacity to perform powerful singular and multiple-joint movements, such knee extensions (Seger & Thorstenssen, 2000) or vertical jumps (O'Brien et al., 2009; 2008) and are most apparent during the ages of 11 to 16 years. However, these hormonal responses are highly variable and do not always follow such a distinct chronological pathway; rather, they are subject to a myriad of environmental and genetic influences (Malina et al., 2004).

Whilst a child's growth conforms to a typical pattern through pubertal stages, biological maturation is subject to considerable inter-individual variation (Ford et al., 2010). Fashioned by both genetic and environmental influences, children will develop in an individual manner,

with associated rates of cellular proliferation and growth largely dependent upon activity and lifestyle choices made throughout the maturation process (Boisseau & Delemarche, 2000). For example, a wide range of social and lifestyle factors may exert influence upon the daily nutritional practices of a prospective sports participant, which are essential to the facilitation of unperturbed growth (Malina et al., 2004). Although a more developed discussion of these topics is beyond that of the current review, it is clear that predictions of maturational age may often be confounded by an array of factors.

The prediction of biological maturity acts as a potentially useful alternative to invasive criterion measures, such as radiological assessment of the skeletal system, or to the evaluation of secondary sex characteristics via the Tanner staging model (Tanner et al., 1978). Indeed, skeletal age and secondary sex characteristics (pubic hair, genitals, testicular volume) are some of the most commonly used indicators of maturation (Malina et al., 2004). Skeletal age is a useful form of assessment from childhood through to adolescence, while secondary sex characteristics may only be used in earlier, pubertal years. There are other indirect assessments that include age at peak height velocity and the predicted fraction of adult height (Beunen et al., 2006; Malina et al., 2004). However, each of these methods requires longitudinal data, which is not always available in applied research studies. Such methods have been used to compare maturity status among children and adolescents (Beunen et al., 1994, 2004; Lefevre et al., 1990).

‘Invasive’ methods, such as Tanner staging and radiological assessments have been used among team sport (soccer) players (Malina et al. 2012). Skeletal age requires a low dose of radiation in order to complete a hand–wrist radiograph (Malina et al., 2004). Skeletal age also

has associated expenses and requires a qualified radiologist and specific equipment. Owing to such limitations, clinical assessment of pubertal status has been adopted. This requires a direct assessment of the stage of genital or pubic hair development. Palpation of the genitals may also be required in order to estimate testicular volume, which has been shown to be sensitive markers of child growth patterns (Tanner, 1972). Such protocols clearly encroach upon the personal privacy of young people and, again, require specific expertise (i.e. physician). Of course, self-assessments of genital development or pubic hair growth have also been adopted yet the validity of such assessments is questionable (Matsudo & Matsudo, 1994).

Owing to the aforementioned issues with both radiological assessments and Tanner staging models, various non-invasive techniques have been developed and used to study young athletes. For instance, some researchers have attempted to model adult stature based upon various somatic dimensions during maturation, such as stature and measures of skin-fold thicknesses (Mirwald et al., 2002; Beunen et al., 1997; Roche et al., 1983). Yet, the samples on which the models were based have often consisted of sedentary or recreationally active participants, which are not analogous to elite team sports players. Therefore, projecting estimations of adult stature based upon typical ‘normative’ values of recreational participants may lead to erroneous predictions of maturational age.

The assessment or prediction of peak height velocity (PHV), defined as the age at which maximal growth is achieved during adolescence (see Mirwald et al., 2002) represents one of the most accurate, non-invasive indications of maturity offset (difference between chronological and biological maturation) and corresponds with the highest rate of

improvement in closed performance measures in adolescent soccer players, such as aerobic capacity and running speed (Philipaerts et al., 2006). Using non-invasive measurements, such as current age, height, sitting height, estimated leg length (height minus sitting height), weight, and interaction terms (i.e. sitting height x leg length), Mirwald et al. (2002) , were able to estimate the chronological age to peak height velocity differential (maturity offset). Although not always evident in talent identification research (i.e. Reilly et al., 2000a; 2000b; Gabbett et al., 2007; Gil et al., 2007; Gravina et al., 2008), it is also advocated that maturational age, as opposed to chronological age, should be accounted for within statistical procedures used to differentiate between players at different stages of puberty (Vaeyens et al., 2006). There are some limitations to the model of Mirwald et al. (2002), such as the non-athletic sample used to create the regression model and, in turn, the wide 0.59 years standard error of the prediction equation. However, it is advocated that such methods are useful surrogates in applied circumstances, potentially affording more opportunities to players who are less mature than their age-matched peers. Indeed, often in talent developmental programmes the technically skilled, yet less mature, players may be overlooked owing to maturity-associated limitations in physical and functional capacities (Malina et al., 2000). In rugby league, players begin to play for a professional club at mid-to-late adolescence (14 years onward). At this stage, the classification of players typically becomes necessary, which would be skewed if overall performance was used as the only guide since this typically favours players who are more advanced in maturity status (i.e. larger and stronger). This increases the likelihood that potentially talented players are unselected (Malina et al., 2004).

A child's optimum exposure to physical and physiological environmental training stimuli can, therefore, be vital during pubertal stages, as increases in bone mineral density of 15-30% and favourable developments in bone size, volumetric density, and bone strength in athletes

trained in competitive sport from childhood have been observed compared to those without such training (Bradney et al., 1998; Kannus et al., 1995; Young et al., 1994). For example, a study by Mejri et al. (2005) demonstrated how physical performance over the course of a competitive season in older elite youth (19 ± 1 years) soccer players yielded an increased target tissue sensitivity to free GH. As a consequence of 31 weeks of competitive training and match play, it appears that young soccer players are afforded a greater affinity for subsequent IGF-1 secretion and, subsequently, increased levels of protein synthesis and substrate availability in order to facilitate the development of contractile tissues (Rivie`res et al. 1989).

Exposure to the appropriate training stimulus is important since changes in sprint performance and endurance capacity are influenced by muscle architecture in children (Ford et al., 2010; Malina et al., 2004; Buenen & Malina, 1988). Anaerobic capacity, and in particular muscular force, has been shown to increase in direct proportion to cross-sectional muscle area (Seger & Thorstensson, 2000). Furthermore, changes in sprint performance as a function of maturity status may be supported by the rapid growth of the central nervous system (CNS) during the first and latter periods of adolescence (Malina et al., 2004). A remodelling of the muscle-tendon complex during maturation, as well as neuromuscular adaptation, has also been suggested to influence anaerobic power during childhood and adolescence (O'Brien et al., 2009; Whittall, 2003; Lin et al., 1997). Such individual changes have clear implications for any assessment of performance and should be accounted for when comparing players of higher and lower ability in the processes of talent identification and talent development.

Research has also shown how more specific resistance training regimes, in particular low resistance - high repetition and high resistance-low repetition programmes, have the potential to induce favourable adaptations in muscular endurance and strength, respectively, among adolescent children (Faigenbaum et al., 1999). Previously, Fournier et al. (1982) had found that three months of sprint training in adolescent males significantly increased the presence of the primary glycolytic rate-limiting skeletal muscle enzyme phosphofructokinase (PFK). The increased activity of PFK ameliorates the process of anaerobic glycolysis for the production of maximal power and anaerobic capacity (Powers & Howley, 2005). Interestingly, no other changes in maximal aerobic capacity ($\dot{V}O_{2\max}$) or oxidative enzyme concentrations were noted and, moreover, during the subsequent detraining period, baseline levels were re-established. The evidence collated from the above studies highlights the sensitivity to different training approaches and the need for specificity in training, even at young ages. The data also show that periods of limited training, such as the off-season, may influence detrimentally the development of sport-specific physiological adaptations during adolescence.

The favourable response of the adolescent athlete to resistance programmes is widely acknowledged, with research demonstrating that such training stimuli is a significant contributor to the development of lean mass or muscle cross-sectional area (CSA) in pre-pubertal and pubertal children (Armstrong et al., 1997; Hetzler et al., 1997; Wenger & Collis, 1987). The introduction of ‘complex training’ (mixture of resistance and plyometric training) or power endurance (PE) programmes may also induce changes in anaerobic power and maximal force production alongside increases in muscle CSA and growth-related androgens (Balciunas et al., 2006; Ingle et al., 2006). The apparent change in muscle CSA, therefore, appears to play an important role in the development of strength and the ability to perform proficiently in a variety of performance tests. Research has shown that the superior

performance of earlier-maturing pubertal soccer players in power-related exercises (standing long jump) is reflected by an increased presence of dihydrotestosterone (male androgen) (Baldari et al., 2009). This supports previous assumptions (see Mero et al., 1991) that early maturation provides additional biological adaptation that is unparalleled by later maturing counterparts at selected chronological stages.

The adoption of the ‘classical’ twin study, whereby monozygotic twins are separated into either a control or an experimental condition (allowing the standardisation of genetic influence and lifestyle practices), can also be used to show the influence of training on biological maturation. For example, Danis et al. (2003) divided a sample of nine monozygotic twins at different stages of pubertal growth into experimental and control groups, with the experimental group completing a six-month period of exercise, comprising three sessions at between 85-120% of lactate threshold. Their findings indicated that whilst genetic predisposition remains the key contributor to improvements in performance during puberty, the training given may contribute between 20-35% for lowered body fat, increase in $\dot{V}O_{2\max}$ and a change in lactate threshold. That is, improvement within each of these variables was significantly greater in the trained versus untrained sibling. Such findings are consistent with the subsequent seminal investigation of De Moor et al. (2007) that found parental genome heritability to account for ~ 66% of current athletic status in 700 dizygotic twin pairs. These findings are likely to be related to superior oxidative enzyme concentrations, and muscle architecture, thus enabling a more efficient usage of oxidative pathways during endurance activity (Ratel et al., 2003). As such, it is clearly important to monitor the training demands of youth participants alongside measurements of growth and performance. Consistent monitoring of training periodization may provide further insight into the general patterns of young team sports players’ performances and growth over prolonged periods.

As the current chapter has demonstrated, whilst there are several factors that will ultimately determine the biological development of young athletes through adolescence, physical activity would appear to be one vital ancillary component contributing to growth and maturation. However, research has shown that exercise regimes given to young athletes should be moderated according to the individual maturational status of an athlete (Ford et al., 2010; Borms et al., 1986).

2.6 Profiling youth performers by ability level

In relation to youth team sport, it is valuable to understand the differences between players of talented status (elite), those deemed less talented (sub-elite), or to be untalented (non-elite) at a given period of time. In response to the paucity of knowledge regarding typical physiological, psychological and anthropometrical profiles of talented and less talented sports players, recent emphasis has been placed upon identifying the potential differences between such populations (Brown, 2001; Gore, 2000). Based upon the understanding that talent may manifest in multiple ways, a variety of physical tests are utilised to identify players worthy of access to talent development programmes.

In British-based team sport, research concerned with differentiating between talented and non-talented players originated in soccer. For example, Reilly et al. (2000a) adopted a multi-dimensional test battery designed to differentiate between elite and sub-elite soccer players during later maturation (mean age = 16.4 years). Anthropometric variables such as body mass, stature, sum of skinfolds and estimated body fat were assessed alongside measures of

performance, such as sprint speed, vertical jump height, agility speed and predicted $\dot{V}O_{2\max}$. Compared to sub-elite players, elite players had lower body fat, were taller, faster over 15 m and 30 m distances, dribbled with more pace and accuracy, possessed a higher predicted $\dot{V}O_{2\max}$ (via the multi-stage fitness test; MSFT) and showed greater agility. Further cross-sectional research in Belgium (groups aged 13, 14, 15 and 16 years), has shown that the distinguishing criteria between elite, and non-elite players differed in the older adolescents (14 and 15 years) compared to their younger counterparts (Vaeyens et al., 2006). The findings of Vaeyens and colleagues, similar to those of Reilly et al. (2000a), identified that endurance performance was the most important factor for elite performance at older ages (16 years), whereas ball skill tests (ball juggling and lobbing) and sprint performance over 30 m distinguished between playing ability in the younger age groups. Subsequent research has also identified the influence of player position as a mediator in the distinction between higher and lower abilities, with forward players characterized by their agility and jumping ability, and midfielders and defenders identified by their endurance or lower body composition, respectively (Gill et al., 2007). However, that Gill et al (2007) sampled players aged approximately 14 to 21 years, prevents their findings being applied to youth participants.

As highlighted above, physical performance developments, such as those represented by superior anaerobic and aerobic conditioning, are to be expected at later adolescent stages. Increases in muscle mass and bone density, coupled with subsequent performance changes, such as an increase in the velocity at lactate threshold, will occur during later pubertal stages (gonadarche), particularly when supplemented with the correct training stimulus (McMillan et al., 2005; Helgerud et al., 2001; Hansen et al., 1999b). Changes in muscle-tendon length have been associated with advanced physical maturity, ameliorating the acceleration phase of

sprint performance (Mero, 2006), and is a common feature of development in most elite youth soccer players (Mendez-Villaneuva et al., 2010). Unfortunately, no research, to date, has explored the relationship between physical growth and physical function in youth rugby league players. This is important since conditioners may design training practices to enhance the physical components that best relate to superior physical performance. For example, it has been commonly found in adults that changes in muscle-tendon structure and stiffness support a decrease in the metabolic cost of running, owing to an increase in ground reaction force per stride (Heise & Martin, 2001). This suggests that muscle stiffness may produce increased elastic energy storage upon foot-to-ground contact (Kyrolainen et al., 2001). It is, therefore, possible that the relationship between indirect measurements of neuromuscular development (counter-movement jump height) and endurance capacity may exist in young rugby league players, thus informing practitioners of how to optimise training procedures.

Aerobic capacity stands as one of the most consistently discriminating factors between higher and lower ability team sports players, particularly at more advanced adolescent stages (i.e. > 16 years). For example, Elferink-Gemser et al. (2006) performed a three-year study that showed elite hockey players (ranging from 12 – 19 years) improved their interval endurance capacity in a positive curvilinear fashion, which decelerated post typical PHV age (13.5 years) but without any associated reduction or severe plateau. In contrast, a decline in the interval endurance capacity of sub-elite players at the age of approximately 14 years was apparent. Many other studies in team sports, such as soccer (Vaeyens et al., 2006; Reilly et al., 2000a) and rugby league (Till et al., 2010; Gabbett, 2009) have highlighted the importance of aerobic capacity at different adolescent stages, which relates to the predominant stress on oxidative energy pathways during match play in these sports (Coutts et al., 2003; Bangsbo, 1994). The time course of development in aerobic capacity, alongside

other markers of performance, amongst youth rugby league players has yet to be identified in research. Furthermore, whilst its relationship to match performance has been identified in youth soccer players (Castagna et al., 2009), this relationship is unknown in youth rugby league players.

Research profiling young players within the rugby codes is sparse, particularly with respect to British-based rugby league. Examples from South African rugby union have revealed that differences in physical attributes such as body mass, stature, calf and upper arm circumferences are apparent in more experienced players than less experienced players between the younger ages of 10 and 12 years (Pienar et al., 1998). In contrast to young soccer players, the evidence provided by Pienar et al. (1998) suggests that anthropometric variables and markers of strength hold greater importance for rugby union players in the above age range. Amongst junior rugby league players, Gabbett (2009) observed differences in aerobic power (under-14) and speed/acceleration (under-16) between players who were either selected to start matches (starters against those who were not (non-starter)). Given the relationship between physical development and anaerobic performance previously discussed (see chapter 2.5), the above results perhaps demonstrate that earlier signs of physical precocity are required to achieve selection in the rugby codes. This is unsurprising considering the physical nature of collision-type sports such as rugby league, which involve repeated tackling actions (Sirotic et al., 2009). Indeed, tackling ability in junior rugby league players is related to the rapid development of speed and lower body power (Gabbett et al., 2010). However, there remains a clear need for further information on the role of physical superiority in talent identification in rugby league.

To date, very little is understood about the rationale for selection or de-selection in the transition to adult performance. Research focusing upon this later stage of development has been advocated since it represents the well-established ‘specialization’ stage in which players may focus explicitly for prolonged periods on refining skills specific to the area of sporting expertise (Ward et al., 2004). Only Gabbett (2009) has investigated the differences in tests for physical ability at the under-18 age group, finding no difference between starters and non-starters in any tests of agility, endurance capacity and skill level. At the adult (> 18 years) stage, evidence supports that skill-based testing will differentiate between rugby league players and has suggested that tests of aerobic power, speed, agility and anthropometric variables, such as skinfold thickness, are weaker predictors (Gabbett et al., 2009). However, more novel tests of physical performance, such as upper-body specific endurance and peak power (Baker & Newton, 2006) or sprint momentum tests (Baker & Newton, 2008) can differentiate between players of higher (National Rugby League, Australia) and lower (second/third division) adult playing standards. Further research evaluating such measures in adolescent populations may, therefore, provide a useful indication of future ability. However, particular measures (including momentum, sprinting force, sprinting power, peak speed and acceleration) will require more developed testing procedures than have been adopted, to date, amongst youth rugby league players. Furthermore, researchers should attempt to perform such tests in real-world settings, using field-based procedures. The use of Global Positioning Systems (GPS) may provide a medium with which to undertake such testing, however, the reliability and validity of certain portable GPS systems for the assessment of sprint performance is currently questionable.

It is worth highlighting that research in youth team sport has used a variety of definitions for the term ‘ability’ or the notion of ‘selection’. For example, studies in soccer (Le Gall et al.,

2010; Figuerido et al., 2009), rugby league (Gabbett, 2002), volleyball (Gabbett et al., 2007) and hockey (Elferink-Gemser et al., 2004) have adopted the use of the outcome of ‘selection’ as an independent (or distinguishing) variable, comprising two sub-levels of either *selection*, or *non-selection*. Specific to soccer, Le Gall et al. (2010) compared anthropometric and fitness performance data of graduate male youth players from an elite soccer academy who, on leaving the institution, were either successful or unsuccessful in progressing to higher standards of play. Players were grouped according to their subsequent international, professional or amateur status. Data were considered relative to their age progression (under-14, -15 and -16) and positional grouping. Overall, analysis revealed that maturity status, body mass, stature, peak concentric torque, maximal anaerobic power, and sprint and jump performance were significantly higher in players attaining international or professional status than those remaining at amateur level. Using a similar two-year follow-up research design, differences in sport-specific skill, body size and chronological age were reported between players ‘dropping out’, ‘maintaining status’ or ‘moving up’ from baseline status (Figuerido et al., 2009). A common approach has also been to select players based upon their elite or non-elite status, determined by the belonging of a player to a professional club. For example, closed skill variables such as shooting accuracy and dribbling speed/accuracy have been found to discriminate between ‘elite’ and ‘sub-elite’ players who were competitively representing professional or amateur clubs, respectively (Vaeyens et al., 2006; Reilly et al., 2000b). Each of the above studies represents a valid method of determining the ‘higher’ or ‘lower’ ability of a team sports player, which may be adopted for future research.

In rugby league, Till et al. (2011) recently reported upon the factors that discriminate between players of regional and national standards. Certain anthropometric and performance characteristics, such as chronological age, 20 m speed, stature, body mass, sum of four

skinfolds and predicted $\dot{V}O_{2\max}$ collectively explained 28.7% of the variance in playing standard. Whilst such results provide practitioners with evidence of potentially measurable facets with which to identify players of higher or lower standard, a further 71.3% of playing ability is accounted for by unmeasured or, perhaps, 'immeasurable' variables. Indeed, facets that potentially determine a young player's future performance may exist within tests that are yet to be developed. Moreover, given that players' entry into talent development programmes is mostly based upon the selectors' discretion, player selection may vary between different sports clubs. That is, as individual clubs require different qualities from prospective players, the criteria of the selectors could be inconsistent, which could account for some of the differences observed between the aforementioned studies.

The use of longitudinal designs (see Mirkov et al., 2010; Figueredo et al., 2009; Huijgen et al., 2010; 2007; Le Gall et al., 2010) indicates the inconsistency in what determines 'higher ability' at different stages of maturation. To use soccer as an example, it has been suggested that agility and motor control, but not power or physical size, differentiate between soccer players reaching professional status or remaining recreational participants during later (> 15 years) adolescence (Mirkov et al., 2010). This is in contrast to other reports in which anaerobic power, sprint performance and stature have been highlighted as discriminators of ability at the same age group (Huijgen et al., 2010; Le Gall et al., 2010). One notable aspect of this research is the geographical diversity of the selected samples, encompassing participants of various nationalities (i.e. Belgium, Netherlands, Serbia, England, France, Spain, Australia and Portugal). In team sport, certain cultural qualities exist that may reflect the way in which players develop through adolescence (Le Gall et al., 2010). It is entirely possible that similar inconsistencies in the required criteria exist at club level, given the disparity in movement demands between different rugby league nations, such as Super

League clubs (Waldron et al., 2011a) and National Rugby League clubs (McLellan et al., 2010) and the potential contrast in coaching philosophies. In this respect, the use of case study approaches (i.e. Gabbett, 2009) may prevent contrasting player attributes between sports clubs from confounding the factors that differentiate selected and unselected players.

In Chapter 2.2 of the current review it was suggested that coaches may select players based upon factors present in the competitive environment, often generically referred to as ‘performance’. Perhaps the main concern for most scientific investigations attempting to differentiate between ability groups using physical performance tests is their definition of what performance constitutes. It is common for researchers to refer generically to the term performance, offering suggestions on how this may vary and develop over maturation (Pearson et al., 2006), without them attending to exactly what it is. Rather, it appears that what is being alluded to are the underlying facets that ultimately determine selection, some of which may be identifiable from players’ performances within real-world, competitive settings. Indeed, numerous authors have begun to investigate the construct validity of various testing procedures, such as shuttle running or explosive power testing, by evaluating their relationship to match-related variables, such as high intensity movement patterns (Mooney et al., 2011; Rampinini et al., 2007; Castagna et al., 2003; Mohr et al., 2003). For example, a study in elite adult Australian Football (AF) by Mooney et al. (2011) showed a direct relationship ($P < 0.01$) between the frequency of ‘ball disposals’ (summation of technical aspects such as tackling, passing, catching, carrying and kicking) and performance on the Intermittent Recovery Test 2 (IR2; see Bangsbo et al., 2008). Whilst such evidence provides an indication that a higher level of endurance performance may aid match performance, the majority of studies have typically assessed adult populations and neglect many potential performance measures such as match-related skill, physiological response to match play and

more refined measures of movement (i.e. sprint frequency). The relationship between performance both within real-world and simulated, closed performance setting requires further investigation, with increased emphasis placed on identifying the performance that most closely relates to the coaches' selection criteria. Such a process may help to reveal the appropriate testing procedures that can help to discern between playing ability levels.

Including the element of competition might augment the use of match-related measures for identifying between lower and higher ability standards, particularly as it underpins all athletic endeavours and players' standards are often judged by their ability to out-perform those in direct competition (Howe et al., 1998; Ericsson, 2003). Although the control of potential confounding factors remains the aim of most laboratory- or field-based assessments of performance, such tests fail to supply direct competition to the participants. Importantly, and despite calls for its inclusion in the talent identification process (Hammond, 2001; Kozel, 1996), its absence defies the nature of sports performance. Consequently, no research has endeavoured to control maximal performance output or to evaluate the way in which players cope when competition is present.

Recent reviews of talent identification in sport have made clear the need to establish the ecological validity of testing protocols. This is achieved through the development of performance measures that simulate the demands of actual competition, and the inclusion of more realistic protocols in order to improve the predictive utility of the measures employed (Vaeyens et al., 2008). Such an issue is particularly pertinent for the assessment of technical ability or 'game-specific skills' (Gabbett et al. 2007; Malina et al., 2005), since many of the protocols have utilised fine motor skill, such as close control dribbling, to differentiate

between pre-determined elite and sub-elite performers (Reilly et al., 2000b; Vaeyens et al., 2006; Malina et al., 2007; Huijgen et al., 2009; Elferink-Gemser, 2004; Falk et al., 2004; Gabbett et al., 2007). However, tests for sport-specific skill in rugby league appear less objective in nature than those used for soccer research. For example, research has commonly used coaches' ratings of players via a Likert-type scale (1 to 5) on selected skill variables, such as passing, tackling and catching technique (Gabbett et al., 2008a). In such cases, players are assessed in the live environment, typically by highly qualified coaches. Based upon two repeated coach ratings of tackling, passing and receiving ability, Gabbett et al. (2008a) reported an inter-class correlation coefficient (ICC) of between 0.84 to 0.94 and typical error (coefficient of variation; CV) of 7.0 to 9.0%. Given the subjective and complex nature of rating the skilled performance of rugby players in the live, dynamic environment, it is vital that the reliability of the testing procedure is thoroughly established. However, the use of relative reliability statistics such as ICCs (as used by Gabbett et al., 2008a) provide a limited insight into the actual agreement between testers and, whilst the CV may represent a measure of absolute agreement, its interpretation has typically been based around arbitrary notions of what is 'acceptable' (e.g. less than 10%) or is not acceptable. The use of the CV is also questionable with ordinal data (such as obtained from a Likert scale) which often displays a skewed distribution (Cooper et al., 2009) that does not satisfy the assumptions of parametric statistical tests. As such, the ability of protocols, such as those described above, to detect sensitive changes in performance may be unrealistic and require re-evaluating.

In order to further develop the area of talent identification and talent development in team sports, real-world measures of performance, such as those apparent within the match setting, should receive greater attention (Vaeyens et al., 2009). Indeed, many authors have commented upon the inappropriate use of the contrived testing environment as a potential

constraint to the identification processes (Waldron & Worsfold, 2010; Lidor, 2009; Falk et al., 2004). Therefore, the focus of the following section is to review how time motion analysis (TMA) might be used to quantify match-related performance in team sports, with emphasis on rugby league.

2.7 Introduction to the game structure of rugby league

Rugby league is an intermittent team sport played between two teams of 13 players with a maximum of 12 interchanges from a pre-determined 18 named players during the course of a match. Each team play out a set of six tackles within which the players must pass the ball in a backwards motion or retain the ball until tackled. A tackle occurs when a player is sent to the ground or is deemed to be stopped from further progression (held up). After each tackle, a 'play-the-ball' takes place in which the player must roll the ball through their legs in a backward motion, thus re-cycling the ball back into play (Eaves et al., 2008). At this stage, the defending team is required to retire 10 m from the point of the play-the-ball or simply to the team's goal line, dependent upon the progress of the attack (Meir et al., 2001). After the completion of each set of six tackles, or when an error or interception occurs, the ball is handed over to the opposition to commence their respective set of six tackles (Sykes et al., 2009). Typically, at the 'five tackle' stage, the ball is often propelled into the air by a kick with the aim of scoring a 'try'. A try is scored when the ball is placed in the try area at the furthest most end of the defending teams' side of the playing field. At the adult level, the match is played over two 40 minute halves with a 10 minute interval between halves. Players are categorized, and often characterized, by a positional role into one of nine positions; props, hookers, second rowers, loose forwards, scrum halves, stand-offs, centres, wingers and fullbacks. Players are further sub-divided into groups as defined by King et al. (2009) as;

forwards, (props, second rowers), adjustables (hookers, loose forwards, scrum halves and stand offs) and backs (centres, wingers and full backs).

2.8 Youth development pathways in rugby league

Young rugby league players in England and Wales are encouraged to participate in variants of rugby league training and competition from the age of 6 (under-7) through to the age of 18. This will typically begin with ‘cub play’; a non-contact, small-sided variant of rugby league match play (under-7s), and develop through the modified games structure (7 to 11 years) towards the contact centred, 13-a-side variant until the age of 13 (Rugby Football League, 2011). During these early periods, players are encouraged to take part in the community game, which is primarily supported by amateur clubs and lower qualified coaching staff (Levels 1 and 2 Rugby Football League coaching awards) within the guidelines provided by the Rugby Football League (RFL). The RFL player development pathway then advocates the passage of players through the Service Area programme which identifies and develops players who demonstrate potential to play at the elite level of the game (RFL, 2011). Given the predominant popularity of rugby league in the condensed Northern regions of England and Wales, the creation of service areas has also enabled the geographical demarcation of development groups. These are set at local authority boundaries, providing the opportunity for specialist coaching delivery and potential identification of players by staff affiliated with local elite clubs (St Helens RFC, 2011). However, whilst the quality of coaching support may improve (Level 3 and 4 RFL coaching award) at this standard, the identification procedures continue as subjective interpretations of performance by the individual coach (Burgess & Naughton, 2010).

At the under-14 age group, players may progress to the regional talent development group in order to receive more refined coaching support and further talent identification procedures. However, up to this age, players will be involved predominantly with their amateur club, supported by lower standard coaching staff (Level 1 and 2 RFL coaching awards). Not until the stage of the under-15 age group, do they become contracted via Scholarship to an elite Super League (the top-class European based league) club. The scholarship stage represents the development through later adolescence (under-15 to -16 age groups) whereby formal match representation (typically increasing with age from five to six games per season) of the elite league club can begin and is supplemented by weekly contact for training and preparation. Players also continue to train and represent their amateur clubs throughout this period and may become involved with national training camps and take part in competitive matches. The final stage of development (16 to 18 years) sees players reaching Academy competition and marks their transition from junior to senior standard. During this stage, players may be accelerated to the full senior squads (less frequently) or play within the academy ranks and reserve squads until selected for first grade standard. Players will receive some form of financial support at this stage, which will depend upon their individual progression.

2.9 Time-motion analysis and physiological demands of team sport

Time-motion analysis broadly describes the capture of information relating to tracked gross and continuous movement of individual athletes or players about the playing surface (Barris & Button, 2008). Such information partly indicates the ‘demands’ associated with a given sport and is vital for sport scientists and applied practitioners in order to inform the specificity of conditioning, recovery and a variety of game-specific training programmes (Di Salvo et al., 2007; Bangsbo et al., 2006). From a youth sports perspective, profiling of

competitive movement demands is less well established, particularly with regard to the development of key movement features over the maturational period. The attainment of such information may reveal the expected time course of readiness for the transition to adult sport, particularly at later pubertal stages. Furthermore, without the documentation of objective evidence of both the physical requirements of team sports players and their physiological responses therein, it remains difficult to monitor the progress of players' performances over a seasonal basis. Whilst research using TMA has been conducted for the last four decades, the techniques of analysis have often varied.

2.10 Manual time-motion analysis methods

An original TMA study conducted by Reilly and Thomas (1976) among elite adult soccer players adopted the use of a manual behavioural recognition technique, akin to notational analysis methods often used to identify the frequency of in-game skills. Such techniques are commonly referred to as 'manual gait analyses' (Mayhew & Wenger, 1985) or 'manual registration systems' (Randers et al., 2010). Using such techniques, the gait pattern of the participant is subjectively interpreted by the researcher and sub-categorized into incremental movement classifications of: standing, backing, walking, jogging, cruising and sprinting. It was deemed appropriate to undertake such an analysis on the premise that quantifying such movement patterns can provide sports coaches with the means to preparing players for match demands or, perhaps, devising work to rest ratios. Although the study of Reilly and Thomas is somewhat dated in its methodological approach to TMA, it remains the foundation for many current analyses, particularly at youth or sub-elite standards, owing to the expense and/or implementation of alternative TMA methods (such as semi-automated multiple camera systems that are discussed in the following chapter).

The approach adopted by Reilly and Thomas (1976) is open to criticism with respect to modern-day techniques. For example, the process of visually interpreting the time spent within the six discernible locomotive categories mentioned above is confounded by a multitude of factors, such as attention bias or simple human error (Bloomfield et al., 2004). In addition, Reilly and Thomas failed to provide any information relating to the explicit definition of each movement category, which have been presented in subsequent manual TMA studies (see below: Mayhew & Wenger, 1985). Whilst subsequent authors did devise and utilise definitions (such as those as presented below) in order to guide their observational analyses, a clear threat to objectivity remains.

Standing: No locomotor movement

Walking: Forwards, sideways and backwards strolling locomotor movement

Jogging: Non-purposeful, slow running where the individual did not have a specific goal for his movements, such as to recover on defence

Running: Combined striding and sprinting; running with purpose and effort

Utility: Combined backwards running, sideways shuffling and jumping

(Mayhew & Wenger, 1985)

Based upon the above definitions, there is also further potential for error to occur in more intense movement categories as an artifact of misinterpretations within previous categories,

such as sprinting. For example, typical definitions of sprinting (see below) can be partially based upon an accurate interpretation of the ‘striding’ gait pattern.

Sprinting: Maximal effort with a greater extension of the lower leg during forward swing and a higher heel-lift *relative to striding*.

(Spencer et al., 2004; emphasis added)

For the study performed by Reilly and Thomas (1976), one ‘trained’ observer was placed at the pitch side with a dictaphone (audio recorder) and was required to verbally dictate the on-going duration of match activities displayed by a single player. It was suggested that reliable measures of the time spent in locomotive categories had been obtained, reporting test re-test reliability coefficients ranging from 0.91 to 0.97. However, issues with reporting mere relative terms of reliability rather than the level of agreement between trials, prevents a more thorough analysis of the reliability whilst using such methods (see Atkinson & Nevill, 1998).

In order for Reilly and Thomas (1976) to quantify the distance that players were travelling within their respective speed zones, average stride patterns of players were recorded prior to competition. It was assumed that by assessing the stride patterns of players whilst self-regulating speed in instructed movement categories, the same information could be applied to competitive scenarios. The result of estimated speed and time spent in that zone was used to calculate distance covered. The obvious issues with such methods, such as the possibility for more enthusiastic and dynamic self-regulation to produce larger stride distances during competitive scenarios, was a factor largely overlooked in early TMA investigations. It is also

common to use 'pre-set velocities', thus basing every player's movements upon an arbitrarily selected speed classification as opposed to individualised categories (see Dogramaci & Watsford, 2006). Audio information was partially corroborated during match play by pre-marking measured distances along the pitch side, thus providing an indication of the distance a player had travelled. The product of the distance travelled (displacement) and the time spent in different movement categories, provided a means of cross-referencing pre-measured locomotive speed. However, issues, such as perspective error, would prevent these methods serving as a credible form of validation (Aughey, 2011). Whilst such methods may appear cumbersome in the modern day, it is surprising that these techniques have been subsequently emulated in both soccer (Bangsbo et al., 1991; Docherty et al., 1988) and other team sports, such as rugby union (Deutch et al., 1998; Mclean, 1992).

Using manually operated TMA systems has many limitations. For example, in order to gather a true representation of an individuals' movement throughout a match, video capture of that player in isolation is required (Bangsbo et al., 1991). The above issue poses a variety of problems for researchers. Firstly, the time required to capture and, subsequently, analyse an individual team of players over a seasonal period may be logistically impractical (Bloomfield et al., 2004). Secondly, the observer (one responsible for interpreting the movement) is said to require habituation prior to implementing the system in practice. This is important since, novice and experienced observers typically exhibit a disparate level of proficiency on a manual coding system, subsequently increasing the likelihood of random error in inexperienced users (Cooper et al., 2009).

Various TMA systems aimed at quantifying individual player movement have been implemented in team sports (Bloomfield et al., 2004; Spencer et al., 2004; O'Donoghue, 2002; Deutsch et al., 1998). For example, Bloomfield et al. (2004) proposed a manual movement classification system (Bloomfield Movement Classification; BMC) comprising an exhaustive list of potential types of movement. Specifically, these were; 14 modes of motion and 3 other movement events, 14 directions, 4 intensities, 5 turning categories and 7 on-the-ball activity classifications. Whilst the BMC provides a detailed insight into the demands placed upon soccer players, there are many associated limitations, such as the reported six hour time period required to analyse a 15 minute segment of play (Bloomfield et al., 2004). Such methods are, essentially, extensions of performance analysis procedures that are now well understood in sports science (see Hughes & Franks, 2004). That is, the systematic observation, recording and reporting of human behaviours in the open match environment.

2.11 Semi-automated computerised tracking of players

Semi-automated computerised tracking of players has recently become a preferred approach to the capture of time-motion characteristics of team based sports. Semi-automated tracking uses visual image recognition software to identify features unique to an individual (Carling et al., 2008; Di Salvo et al., 2007). Examples of such features may be colour, shape or size of the participant (Carling et al., 2008). Cameras are situated in specific areas around the perimeter of the playing surface and synchronously digitised and calibrated in order to calculate the distance and speed of players' movements. The use of such sophisticated

systems is apparent only within elite sporting contexts, largely due to the associated costs and logistical implications, therefore limiting their use at less spectated venues, such as that associated with youth team sport.

Previous work appears to have confirmed the reliability of commercially available multiple camera systems (MCSs), such as “Prozone”, for match recording the displacement of players during team sport performance, reporting no mean bias ($P < 0.05$) and 0.4% error in comparison to the assessment of pooled running speeds assessed via timing gates (Bradley et al., 2007; Di Salvo et al., 2006). More recently, a study by Randers et al. (2010) compared MCSs to Global Positioning System (GPS) devices (5 Hz and 1 Hz) and a video TMA system. A clear disparity between both of the GPS systems and the MCS was reported, with CV values ranging from 7% to 12% and r -values of only 0.62 for total distance covered during the match (see section for 2.16 for further details of TMA reliability). Of particular note were the large differences between systems with regards to distance covered in separate locomotive categories. For example, the MCS reported the distance in high intensity running to over-estimate the GPS (5 Hz) calculations by 0.63 km and the MCS by 0.81 km. Such a finding deconstructs the previous comparisons made by authors between studies using different modes of TMA (i.e. Castagna et al., 2009). Moreover, authors suggesting an increase in movement intensity based upon comparisons of research using MCS compared to manual methods (i.e. Di Salvo et al., 2007) should remain aware that such changes in movement intensity might be much larger than originally anticipated.

Computerised tracking is also often difficult to conduct where competitors maintain a close proximity and may therefore frequently (3% to 42% of the time) require human intervention

(Di Salvo et al., 2009). Figueroa et al. (2006) have discussed the issues associated with the specific problem of lighting changes and changes in motion velocity, making MCS analysis difficult with sports necessitating close proximity of players. Whilst the limitations of MCS should be recognized, the sampling rate of 7.5 to 25 Hz (with the option to increase) remains far superior to alternative measures of TMA, such as GPS.

2.12 Match demands of rugby league

The use of manual TMA methods to describe match demands in rugby league remains common practice. For example, King et al. (2009) compared the differences between forwards, adjustables and outside backs (positional groupings) from the National Rugby League competition (NRL, Australia). A hand-based notational system was utilised, quantifying distance and intensity of movement for standing, walking, jogging, striding and sprinting in both backwards and forward motions. The positional groups differed ($P < 0.05$) in relation to the distance covered with outside backs travelling $6,265 \pm 318$ m and adjustables covering $5,908 \pm 158$ m during matches. Both these positional groups covered more distance than that of the hit-up forwards ($4,310 \pm 251$ m). The percentage of time spent within high intensity activity (striding and sprinting) was different ($P < 0.05$) between backs (~19%), adjustables (~15%) and forwards (~12%). These percentages changed between first and second half periods, particularly for outside backs (a significant 19% to 14% change). The results presented by King et al. (2009) under-report that of previous analyses using manual systems in rugby league. For example Meir et al. (2001) reported much larger estimations of work performed during matches, with distances of 10,000 m covered by backs and 8,500 m by forwards. Furthermore, jogging backwards (~ 2%) and sprinting movements (~ 0.5%) were shown to be higher in forwards than backs, which differs to the data of King

and colleagues (2009). However, the sample size in the study of Meir and colleagues was limited to four players during two matches. Meir et al. (2001) also failed to provide sufficient information regarding the TMA system used and how distance was calculated. Therefore, such results should be viewed with caution since no indication of reliability or validity of the system used was provided.

To date, few studies have adopted the use of MCSs in rugby league (Sykes et al., 2011, 2009). Using a sample amalgamating players from both Super League (European based league) and National Rugby League (NRL), Sykes et al. (2009) reported distances of $8,142 \pm 680$ m (outside backs), $8,800 \pm 581$ m (pivots), $8,688 \pm 405$ m (props) and $8,685 \pm 547$ m (back rowers). Speed zones were classified as standing, walking, jogging, running, high intensity running and sprinting (Rampinini et al., 2007). Outside backs spent the most time in high intensity running (2%) and sprinting zones (0.6%) compared to other positions, particularly compared to forwards. That backs had 3.8% less time spent in contact or their peripheral pitch position afforded greater space with which to develop a higher rate of linear motion probably explains these observations. In contrast, subsequent analyses using GPS technology have showed outside backs cover $6,917 \pm 1,130$ m and adjustables to cover $6,093 \pm 1,232$ m, which was greater than forwards ($4,181 \pm 1,829$ m) (Waldron et al., 2011a). Such findings are similar to those reported for players competing in the Australian NRL competition using an identical 5 Hz GPS device (McLellan et al. 2011; 2010). Whilst some of the difference between distances covered using MCSs or GPS may be a result of the discrepancies reported between methods of TMA (see Randers et al., 2010), this is unlikely to account for differences of such large magnitude, particularly in the forward group (8,688 vs. 4,181). Therefore, the methodological approach of Sykes et al. (2009) might explain the variation found in distance covered, in which all interchange replacements (commonly found

with forwards) were continually analyzed, thus amalgamating two potential performances of substituted players. Subsequently, given the predominant role of interchanged players (forwards mean match time = 44.2 ± 19.2 minutes), previous estimations provided by Sykes et al. (2009) regarding distance covered for forwards are likely to overestimate values of distance covered for a single player.

The intermittent role of the forward position in rugby league necessitates the use of relative distance rather than ‘absolute’ distance covered; that is, the use of outcome measures such as total metres covered per minute ($\text{m} \cdot \text{min}^{-1}$) and relative distance within speed thresholds. For example, Waldron et al. (2011a) showed higher $\text{m} \cdot \text{min}^{-1}$ in forwards ($95.2 \text{ m} \cdot \text{min}^{-1}$) and adjustables ($94.2 \text{ m} \cdot \text{min}^{-1}$) compared to outside backs ($89.6 \text{ m} \cdot \text{min}^{-1}$). Furthermore, within both medium and high intensity activity, the relative distance covered was either the same or higher in forwards and adjustables compared to outside backs. Therefore, forward and adjustable players competing in the Super League competition appear able to maintain the same or higher intensity than outside backs, albeit for briefer periods. An additional finding was showed no differences ($P > 0.05$) between positions in the number of sprints performed per minute of playing time (approximately $0.3 \text{ sprints} \cdot \text{min}^{-1}$). Using alternative methods of TMA, Sirotic and colleagues (Sirotic et al., 2009) reported higher overall values of $108.6 \text{ m} \cdot \text{min}^{-1}$ and values of $36.7 \text{ m} \cdot \text{min}^{-1}$ and $32.5 \text{ m} \cdot \text{min}^{-1}$ for distance in high-intensity running during the first and second half of NRL competition, respectively. Of note, within the same study, a comparable amount of sprints performed per minute (approximately $0.3 \text{ sprints} \cdot \text{min}^{-1}$) were reported. Notwithstanding the different methods of TMA applied, such results appear to show superior relative high-intensity running in the NRL ($> 13.1 \text{ km} \cdot \text{h}^{-1}$) than Super League performance (Waldron et al., 2011a). However, the results of Sirotic and colleagues are questionable since a sample using various positional groups was used with limited

information regarding the actual positions being analyzed. A more recent analysis using GPS technology in the NRL (McLellan et al., 2011) showed lower total distances covered in backs (5,700 m) but more amongst forwards (4,982 m) compared to Super League backs (6,700 m) and forwards (4,181 m), respectively (Waldron et al., 2011a). Whilst McLellan and colleagues failed to present relative metres covered in NRL players, given the reported mean playing periods, the metres covered per minute of playing time appear similar in forwards from both the Super League and the NRL competitions. However, based on the same study comparison, players from the outside-back positions still possess higher relative running distances in the Super League. Such comparisons perhaps demonstrate that the alleged superiority of NRL players compared to those from the Super League is not reflected in match-running performance. An overview of the above comparisons is outlined in Table 2.1.

A follow-up study performed by Sykes et al. (2011) adopted the use of relative intensity measures, such as overall distance and high intensity distance covered per playing minute ($\text{m} \cdot \text{min}^{-1}$), to highlight the potential influence of fatigue during matches. Notwithstanding the shortcomings of arbitrary speed classification that were employed within the analysis, progressive decline in locomotive rate was shown within each half of the match, with the lowest intensity periods occurring in the final quarter of the game. A further analysis of positional groups indicated a larger percentage decline in very high intensity locomotion in props (75%) compared to other positional groups (~ 31% to 46%). However, whilst positional groups were not statistically compared, the overall values of high intensity running throughout a match appeared similar between groups, in which a worst case difference of $\sim 2 \text{ m} \cdot \text{min}^{-1}$ was reported in the final match quartiles of back rowers ($14.8 \text{ m} \cdot \text{min}^{-1}$) and pivots ($17.8 \text{ m} \cdot \text{min}^{-1}$). It is noteworthy, however, that whilst the authors attempted to control for disparities in playing time between positional groups, the presence of any interchanges made

by the forward players involved was not accounted for. Substitutions afford players a clear period of passive recovery in which to re-synthesise high-energy phosphates required to support anaerobic activity (i.e. higher intensity work) and offer a period in which to spare endogenous fuel sources for later match stages (Saltin, 1973). Indeed previous work in soccer has showed the effect of substitutions on match running performance, indicating the attainment of higher intensities during later periods in such players (Carling et al., 2010). At a fundamental level, it is also erroneous to sample lower frequency actions such as high intensity movements, from a period of one minute (as compared to 20 minutes) based on the likelihood that the player in question was disengaged in the match during this time. Therefore, authors should look beyond comparing fatigue profiles between players with entirely unrelated roles within a match.

Table 2.1. Overview of time motion analyses in rugby league

Author	Level (n)	TMA mode	Approx. distance (km)	Distance HIT (km)	Sprints	Zone derived from
Meir et al. (2001)	University (4)	Manual	10	-	-	n/a
Sirotic et al. (2009)	NRL/NSW Premier (17)	Trak Performance	8.4 – 8.2 (pro)	2.7	24 (pro)	Rampinini et al. (2007)
King et al. (2009)	NRL (3)	Manual	4.3 - 6.3	-	-	n/a
Sykes et al. (2009)	SL/NRL (78)	MCS	8.1 - 8.8	-	-	Rampinini et al. (2007)
McLellan et al. (2010)	NRL (15)	GPS	4.7 – 5.7	0.6 - 0.9	-	Deutsh et al. (1988)
McLellan et al. (2011)	NRL (17)	GPS	4.9 – 5.5	0.3 - 0.6	11 - 18	Deutsh et al. (1988)
Sykes et al. (2011)	SL/NRL (59)	MCS	8 (pro)	1.4	-	Rampinini et al. (2007)
Waldron et al. (2011a)	SL (38)	GPS	4.1 - 6.9	0.5 - 1	14 - 35	Rampinini et al. (2007)

Note: pro = projected value; TMA = time-motion analysis; MCS = multiple camera system; GPS = Global Positioning System; NRL = National Rugby League; HIT = High intensity ranging from 13.1 – 14.4 km·h⁻¹; Sprints =21-24 km·h⁻¹.

Rugby league is characterized by intermittent explosive movements such as repeated sprinting (Waldron et al., 2011a; Sirotic et al., 2009), thus necessitating sporadic anaerobic energy contributions. Previous research has also reported lactate concentrations of 8.4 mmol·l⁻¹ in rugby league (Coutts et al., 2003), which is similar to that found in soccer players (9.5 mmol·l⁻¹; Ekholm, 1986) during competitive matches, suggesting a rise in anaerobic glycolysis and a requirement to tolerate the onset of lactic acid accumulation. Intense, explosive movements such as tackles and hit-ups, also characterize the sport of rugby league (Austin et al., 2011). Performance analysis of elite rugby league has showed collisions (as both the tackled and tackler) to range from 0.3 (~ 24 total) to 0.71 (~ 57 total) per minute of playing time, which is consistently higher in forwards (0.63 - 0.71 collisions per minute) compared to backs (0.31 - 0.5 collisions per minute) (Twist et al., 2011; McLellan et al., 2011; King et al., 2009).

2.13 Youth rugby league demands

Whilst the match demands of the adult rugby league population have received reasonable attention, little is understood regarding the match environment from a youth context. As such, youth rugby league practitioners have only a modest concept of match demands and limited information with which to prepare young players for transitioning through talent development (talent development) pathways. This is particularly pertinent to the identification of young talented team sports players since match-related performance appears to underpin judgements of playing ability (Vrljic & Mallet, 2008). Such information also develops current performance profiling methods in favour of ecologically valid measures of competitive performance (Waldron & Worsfold, 2010; Lidor, 2009; Vaeyens et al., 2009; Falk et al., 2004). Therefore, evidence relating to the requirements of the elite competitive

environment in youth players would be beneficial to the talent development process, enabling practitioners to provide young players with the appropriate training stimulus and identify facets of performance that potentially characterize superior ability.

Whilst investigations on the competitive movement demands of youth rugby league players are limited, one previous study has reported mean HR values of approximately 87% of maximum for elite youth (under-17 group) players during competitive matches (Estell et al., 1996). Furthermore, Deutsch et al. (1998) reported distances of between 4,200 m (forwards) to 5,600 m (backs), with a maximum of 4.1% of time spent at high intensity in under-19 rugby union players. It is likely that the time spent performing static tasks during the game, such as rucking, mauling and scrummaging is responsible for the comparable drop in intensity in comparison to rugby league research. In addition, the element of contact (tackling) may also diminish the development of higher velocity movement in collision sports (Sykes et al., 2009). Therefore, given the dearth of empirical evidence, it would be useful to gain further insight into the internal and external demands of elite youth rugby league.

Technical proficiency during match play also has a predominant influence on the holistic development of younger rugby league players and may differentiate between playing ability; however, only minimal evaluation of technical demands within the above sports is currently available (Gabbett et al., 2008a). Examples of these characteristics may be performance indicators such as the success of tackles, carries and passes in rugby league (Sirotic et al., 2009).

In relation to the identification and development of talented young team sports players undergoing maturation, it is of further importance to comprehend the time-course of development in match performance and the potential for variation therein. Understanding such information may help to inform coaches of the correct training strategies to adopt in order to provide optimal physiological and motor-skill conditioning. However, there is no research, to date, that has evaluated longitudinal changes in match performance, resulting in limited evidence of potential developments in this fundamental requirement during later adolescence. Furthermore, the differences in match performance between coach-selected and coach-unselected players have not been addressed, which could be used to supplement the understanding of factors that differentiate between players of higher and lower ability over developmental periods.

2.14 Issues with the identification of high intensity

Whilst high intensity performance remains a central method of determining match demands and fatigue therein (Bradley et al., 2009; Mohr et al., 2003), there are current concerns over the determination of 'high intensity movement' within TMA studies. Indeed, there is little consensus between studies with regard to the classification of high intensity movement, which, for example, has varied from 13 km·h⁻¹ (Mallo et al., 2007) to 19.1 km·h⁻¹ (Di Salvo et al., 2007) in adult soccer. In rugby league, this has also ranged from 13 to 14.4 km·h⁻¹ (Sirotic et al., 2009 & Sykes et al., 2009, respectively). A notable difference between each TMA investigation is the mode of analysis, such as MCSs or GPS technology, and the source of speed zone determination (Table1). Studies using GPS to investigate sprinting activity in team sport (i.e. McLellan et al., 2011; 2010; Gabbett et al., 2011a; Randers et al., 2010; Coutts, et al., 2009), commonly provide justification for sprinting or very high intensity

running categories based upon numerous dated recommendations that have been previously constructed using timing gates or manual chronometry methods (Reilly & Thomas, 1976, Docherty et al., 1988; Mclean, 1992; Bangsbo et al., 1991; Deutsh et al., 1998). An example of typical speed categories are;

- Standing ($< 0.2 \text{ m}\cdot\text{s}^{-1}$)
- Walking ($0.2\text{-}1.9 \text{ m}\cdot\text{s}^{-1}$)
- Jogging ($2.0\text{-}3.9 \text{ m}\cdot\text{s}^{-1}$)
- Running ($4.0\text{-}5.4 \text{ m}\cdot\text{s}^{-1}$)
- High Intensity Running (HIR; $5.5\text{-}6.9 \text{ m}\cdot\text{s}^{-1}$)
- Sprinting ($\geq 7 \text{ m}\cdot\text{s}^{-1}$)

(Rampinini et al., 2007)

Such methods are problematic on two counts; firstly, timing gate speed does not compare closely with speed measured using most GPS devices (Petersen et al., 2009). For example, 5 Hz GPS devices have been reported to underestimate criterion measured distances (20 m) by approximately 15% during sprinting activity (Petersen et al., 2009). Secondly, such an approach to speed zone determination disregards the variability in running speeds between individual athletes and, importantly, fails to differentiate between internal and external measures of load (Viru & Viru, 2001). That is, two players running at the same velocity are likely to be experiencing a different physiological exertion. Therefore, the term ‘high intensity’ is simply denoted by the external characteristics of running speed, without

consideration of the physiological demand placed on a given athlete. Subsequent prescription of training demands based solely upon external characteristics may either under or overestimate an individuals' performance capacity.

Positional differences in sprinting activity may be obscured or exaggerated by the use of arbitrary speed zone determination. As discussed by Abt and Lovell (2008), the link between external and internal load is not fixed across individual athletes, since a speed of $5.5 \text{ m}\cdot\text{s}^{-1}$ may induce only medium intensity exercise in certain individuals. In response to such a possibility, Abt and Lovell (2008) determined the running speed of elite soccer players associated with various physiological loads. The authors adopted the use of the ventilatory threshold, or more accurately, the ventilatory turn point. Such a threshold reflects the point at which the linear relationship between oxygen uptake and the rate of ventilation is disrupted by a disproportional rise in the partial pressure of carbon dioxide (PCO_2). A subsequent chemoreceptor response to a rise in PCO_2 induces a change in ventilation outside of the typical linear relationship. This stage has been shown to occur at a similar, albeit marginally delayed, time period to the lactate turn point and, more crucially, delineates the threshold between moderate and 'high' intensity exercise (Jones & Doust, 2001). Using the speed associated with ventilatory turn point in elite soccer players, Abt and Lovell (2008) showed the potential 167% under-prediction of the distance run at high intensity in comparison to the higher $19.8 \text{ km}\cdot\text{h}^{-1}$ thresholds. Consequently, high intensity thresholds should be scaled to the individual athlete, considering the interaction between external and internal load.

When basing TMA research upon arbitrary speed classifications, a further problem relates to the expression of intensity as the percentage of time spent within locomotive categories (see

Spencer et al., 2004; Meir, 2001; Reilly & Thomas, 1976). In order to compare between first and second halves of a match period, one should remain aware that, in absolute terms, the actual distance covered or work performed by a player may stay the same, even though relative time spent is altered. For example, an arbitrary value of 19% of time in high intensity in the first half of a match may, indeed, translate to an equal distance covered even if 14% of time is spent within the second half. Put simply, the percentage of time can alter without true distance covered doing the same. When expressed in such a manner, it is possible that indices of fatigue during a match will be erroneous. However, whilst the above is true, assuming that all other speed categories demonstrate similar changes over time, it is feasible that fatigue could be monitored by the percentage of time in high intensity. In such a case, decrement in performance or potential 'fatigue' is determinable since, regardless of the distance being covered by an observed participant, changes in the relative time spent in high intensity show a true change in work done. Nevertheless, researchers should remain aware of the limitations associated with reporting match running characteristics in this way.

One potential implication of individualising speed thresholds in team sport athletes is the anticipated changes in fitness parameters as a function of season time, such as aerobic capacity (Gabbett, 2006). This is particularly pertinent to studies in youth team contexts since, during maturation, an improvement in aerobic capacity and the speed associated with high intensity activity can be expected (Impellizzeri et al., 2009; McMillan et al., 2005). Furthermore, sprint performance may also vary over teenage years (Mendez-Villanueva et al., 2010; Gabbett, 2002). It is common to individualise sprinting zones for TMA studies (using GPS as the method of TMA) based upon measurement of linear speed using chronometry methods, such as infra-red timing gates (Harley et al., 2010). However, as discussed previously, timing gate speed will often over-predict GPS measured speed. Therefore, it is

likely that such research using GPS during match time will underestimate sprint performance, since participants will fail to reach the higher timing gate speed zone. The lack of research to justify the use of GPS models to monitor sprint performance may be one issue precluding the simple use of the devices to determine linear speed prior to data collection during match play. Further research is therefore required in order to determine the utility of current GPS models to assess sprint performance and quantify the magnitude of error between such devices and chronometry methods.

2.15 Measurement of 'load' in team sport

In addition to the analysis of human motion, measurements of internal physiological load are now becoming commonplace in the competitive environment. Reports have highlighted the intermittent and predominant aerobic nature of team sports, in which heart rates (HR) corresponding to approximately 80% to 86% (Waldron et al., 2011a; McLellan et al., 2010; Coutts et al., 2003) of maximum values have been reported in adult rugby league players. Moreover, such heart rates indicate a substantial metabolic demand, averaging intensities of 70% to 80% of maximal oxygen consumption (Coutts et al., 2003).

The use of HR to interpret physiological load in the match environment enables the inference of 'internal load' (Virtanen & Virtanen, 2001). The notion of 'load' can be assessed within most exercise environments and is described as the product of volume and intensity of work and reflects the relative physiological stress induced by exercise (Virtanen & Virtanen, 2001). Although peripheral blood markers of fatigue derived from capillary and venous samples, such as of lactate or potassium accumulation (Krustrup et al., 2006; Bangsbo et al., 1996) remain

inherently useful in the description of exercise intensity, such measures are often too cumbersome for use in applied match settings (Impellizzeri et al., 2005) and poorly reflect equivalent concentrations at tissue level (Krustrup et al., 2006). Certain non-intrusive measures based upon average HR recordings, such as the training impulse method (TRIMP) have been devised in order to establish exercise load (Bannister, 1991). However, TRIMP scores are likely to underestimate the physiological load of intermittent exercise bouts when predicted from the HR – blood lactate concentration during continuous exercise (Akubat & Abt, 2011). The development of further HR measures has made it possible to account for the variability, and often disproportional, time spent within different thresholds of maximal HR intensity during stochastic sports. For example, the load experienced by players within a competitive environment can be evaluated based upon the original methods of Edwards (1993) (see below).

$$\begin{aligned}
 &(\text{Duration in zone 1} \times 1) + (\text{Duration in zone 2} \times 2) + (\text{Duration in zone 3} \times 3) \\
 &+ (\text{Duration in zone 4} \times 4) + (\text{Duration in zone 5} \times 5)
 \end{aligned}$$

Where zone 1 = 50% to 60% of HR_{\max} , zone 2 = 60% to 70% HR_{\max} , zone 3 = 70% to 80% HR_{\max} , zone 4 = 80% to 90% HR_{\max} , and zone 5 = 90% to 100% HR_{\max} (Edwards, 1993).

The so called ‘summated heart rate’ method provides an arbitrary unit of exercise load and preferentially weights the time spent within higher intensity thresholds. This method has been used to evaluate training load during small-sided games (SSGs) (Coutts et al., 2009; Impellizzeri et al., 2004), various sport-specific training drills (Alexiou & Coutts, 2008) and

to quantify 'match load' (Waldron et al., 2011a). Notwithstanding some of the associated limitations of HR as a marker of physiological load, owing to factors such as dehydration and circadian rhythm (Achten & Jekendrup, 2003), under controlled conditions, such measures offer a practical field-based tool for the detection of training or match load. Similarly, the rating of perceived exertion (RPE) relates to HR and blood lactate during sub-maximal exercise, thus enabling estimations of exercise intensity using a subjective scale (Robertson & Noble, 1997). Based upon such perceptual measures, an alternative method of determining 'load' has been the session-Rating of Perceived Exertion (RPE). Session-RPE is the product of intensity (0-10 scale) and the duration of exercise (time on pitch). Initially posited by Foster et al. (2001), this method acts as a simple method of estimating exercise load and has been validated against that of the summated HR method over a variety of exercise contexts (Minganti et al., 2010; Lambert & Borresen, 2008; Herman et al., 2006; Day et al., 2004). A variety of studies have showed that session-RPE can explain a large degree of the variance in summated HR and blood lactate during team sport performance (65% to 80%), thus demonstrating the use of this measure in order to establish the workload experienced by players in the competitive environment (Coutts et al., 2009; Alexiou & Coutts, 2008; Gabbett, 2006; Impellizzeri et al., 2004). Of course, various issues with using perceptual measures of training or match load exist, such as familiarization. For example, Buckley et al. (2000) demonstrated a trial order effect on the reported reliability of steady state cycling performance when the intensity was guided by RPE values alone. Thus, an increase in the degree of experience with an RPE scale appears to improve the reliability of human effort perception. Whilst Foster et al. (2001) suggest that no familiarization should be used with measures of global RPE (0-10 scale), it is clear that the same effect may be present.

The practical application of load measurements in adult team sport has centred upon prescription of exercise thresholds in relation to injury prevalence and avoidance (Gabbett, 2004a; 2004b), particularly in rugby league where a strong relationship ($r = 0.86$) between units of training load and training volume has been reported. It is also of great importance to monitor habitual exercise load, within both competition and training, amongst youth team sport players. For example, improvements in aerobic capacity and neuromuscular force in both youth and senior rugby league cohorts can be monitored and differentiated via the response to a given training load (Gabbett, 2006). Indeed, quantification of training load, such as that of SSGs, is useful in order to understand typical performance responses to a given stimulus, which has been clearly evidenced in endurance athletes (Midgely et al., 2007). However, in youth team sports players, the long-term responses to training stimulus are poorly understood and may be more difficult to identify given the multidimensional nature of performance in team sport (Brink et al., 2010). In youth sports, much less is understood regarding the cumulative influence of match and training load upon maturation and development of playing ability. This would be a particularly useful progression to research pertaining to the maturational process, where the extent to which fatigue manifests and, subsequently, influences performance has been rarely considered. Indeed, exposure to optimal training and match volume may characterize one ancillary component of the talent development process. Measurement of load during both preparation and competition has also been shown to correlate to injury incidence and may coincide with ‘fatigue’ over seasonal periods (Brink et al., 2010; Gabbett et al., 2004a). Studies have showed the detrimental effect of cumulative training units upon various fatigue indicators in youth soccer players, such as decrements in muscular function and psychological status or the presence of salivary glucocorticoids (Robson-Ansley et al., 2009). In youth performers, the effects of long-term fatigue may further translate into performance deficiencies during match conditions, which

could be modelled over consecutive performances. Furthermore, differences in the perceptual and HR responses of talented and less talented players to match play may also provide a global indication of the endured physiological stresses over maturational periods.

2.16 Reliability and validity of field-based measurement

Within all scientific disciplines, an important feature of any investigation is the valid and reliable measurement of selected dependent (outcome) variables (Atkinson & Nevill, 1998). The measurement of outcome variables is often carried out using technical equipment that, for example, may be calibrated on a continual basis using known quantities or magnitudes in order to maintain the accuracy of the measured values. Sport scientists using such equipment to quantify performance related measures require assurance that the tool being used has the ability to provide a measure that reflects what it is designed to measure (Nevill et al., 2007; Atkinson & Nevill, 1998). Furthermore, in order to monitor performance on repeated occasions and compare measured values over time, the user needs to be aware that the error associated with a given measurement is minimal or small enough to allow systematic changes in the selected variables to be detected.

As a result of the many field-based testing procedures commonly adopted in sport science (Chamari, 2004), researchers are often concerned with the degree of sensitivity that such devices can provide for human performance assessment (Currell & Jeukendrup, 2008). Whilst many laboratory-based measuring devices provide sensitive indications of minor changes in human response to exercise (Currell & Jeukendrup, 2008), replicating such accuracy can be complicated in the field, owing to numerous inconsistencies in environmental conditions and restricted mobility of measuring devices. Such factors limit the

control of ‘confounding variables’ during scientific investigation which may adversely influence the consistency of desired measures (Tabachnick & Fidell, 2006).

2.17 Reliability and Validity of TMA systems with reference to GPS

The recent advent of TMA instruments, such as those discussed in previous chapters, has enabled a greater understanding of the demands associated with the match and training environment. Portable GPS devices, in particular, have received broad attention in the disciplines of sports science (Aughey, 2011; Carling et al., 2008). As such, a recent body of research has emerged pertaining to the validity and reliability of portable GPS devices. Validation of TMA instrumentation remains complicated since it is difficult to quantify the true or ‘criterion’ measure of variables such as locomotive speed and acceleration (Carling et al., 2008). So called ‘criterion validity’ represents one of numerous validation processes and necessitates the comparison of a selected method of measurement to a ‘gold standard’ counterpart (Currell & Jeukendrup, 2008). Alternative assessments of validity also exist, one of which can be referred to as ‘concurrent validity’. Concurrent validity plays an important role in the assessment of measuring equipment since it may be useful to understand the degree of parity between a globally accepted measure and one that has potential for similar uses (Hopkins, 2000). Such investigations are also commonly termed method comparisons and only partially elucidate the level of validity associated with a measuring tool. Each of these will be discussed in the current section.

As previously discussed, it is prudent for the current review to discuss GPS as a preferable mode of TMA since such methods may be used to quantify the physical demands of competition in team sport performance. A portable GPS system functions using 27 satellites

that orbit around the earth. The GPS device is programmed to receive a radio signal, emitted from an orbiting satellite at the speed of light (Larsson, 2003). An atomic clock is fitted within each orbiting satellite and time-matched to a clock held within the portable receiver. The time taken for the signal to travel between each instrument can subsequently be determined (Schutz & Herren, 2000). The product of the known speed of the signal and the lag in time between the two synchronized clocks determines the distance travelled between the satellite and the receiver. So called ‘pseudo-ranges/distances’ can be projected spherically from the connecting satellite, placing the receiver within an encapsulated radius. Using further satellites in concert (a minimum of four) the exact position and subsequent navigation of an object on the earth’s surface can be established (Macleod et al., 2009). The intersection between the projected spherical surfaces, combined with logical assumption that the receiver is positioned on the earth’s surface, provides an indication of the position on earth.

Speed may be calculated, firstly, using serial changes in positional plots over a given time period or, secondly, using a Doppler shift method (see Townshend et al., 2008). The Doppler shift method calculates changes in the frequency of transmitted radio signals, attributable to the movement of the GPS receiver (Schutz & Herren, 2000). Both the Doppler shift method ($r = 0.99$) and positional measures ($r = 0.99$) relate strongly for assessment of speed whilst walking and running over- ground (Townshend et al., 2008).

In relation to the validity of portable GPS devices, early investigations of GPS assessment of human locomotion (Schutz & Chambaz, 1997) (pre-May 2000) were subject to the artificially created ‘selective availability’, a purposeful error administered by the American government, thus causing larger magnitude of noise in the GPS signal until it was discarded after May

(2000). Since the removal of selective availability, GPS devices have been rigorously investigated for human movement assessment, particularly in the sports performance field. Witte and Wilson (2004) reported upon 1 Hz GPS assessment of cycling speed over curved and linear pathways, concurrently comparing speed measured via a calibrated speedometer. GPS measurements of constant speeds travelled along straight trajectories compared more accurately to pedometer values than recordings over curved pathway, where GPS measurements were shown to under-predict pedometer speed. However, 43% of values were reported to have errors exceeding $0.2 \text{ m}\cdot\text{s}^{-1}$ on linear paths, demonstrating a negligible difference in accuracy when compared to previous reports conducted prior to selective availability (Schutz & Chambaz, 1997). The apparent difference between straight and linear courses appeared to be linked to the sampling rate of various early GPS models. When positional plots are recorded at lower frequencies (i.e. 1 Hz) the resultant comprehension of speed and distance may be skewed, since large changes in dynamic human movement may occur during transient ‘blank’ periods. Furthermore, on a curved pathway appears to underestimate distance compared to a linear distance of the same magnitude (Gray et al., 2010). This is caused by the leaning motion of the athlete, resulting in the upper-torso (where the GPS unit is positioned) travelling closer to the locus point and, thus, covering less distance and under-calculating speed.

A second issue to consider whilst using any GPS measurement relates to the geometrical position of the GPS receiver on the earth’s surface (Witte & Wilson, 2004; Larsson, 2003). Depending upon the time of the day and the subsequent orbit of selected satellites, the area in which spherical pseudo-ranges intersect will either increase or decrease in clarity. That is, when the number of satellites available is few (minimal of four required) the chance of each of these having a favourable position in which to cross pseudo-ranges is low (Jennings et al.,

2010). Consequently, when the geometric pattern of the satellites becomes skewed, the area that the true position on the earth's surface could be becomes 'diluted' and requires a measurement indicative of the capacity at that time for erroneous readings. A term dilution of precision is often used to describe the description of such phenomena.

Dilution of precision (DOP) can be referred to as either vertical or horizontal (HDOP). In human movement it is important to gain readings as near to an arbitrary value of 1 as possible in order to satisfy the optimal conditions for analysis. It is notable within many analyses that the DOP is not quoted and remains unaccounted for (see Coutts & Duffield, 2010; Duffield et al., 2010; Macleod et al., 2009), leading to unaccounted random error and, subsequently, influencing speed determination (Witte and Wilson, 2004). For example, when receivable satellites cluster in close proximity, the determination of the GPS receivers' most logical placement (pseudo-range) is markedly increased, thus increasing the probability of erroneously identifying serial positional fixes. In turn, the accuracy with which speed and distance of a GPS receiver is calculated will be subjected to a larger degree of random error.

In accordance with the continual development of GPS technology, the type and sophistication of GPS models used between studies often varies. Elements such as, the sampling rate (1 Hz to 15 Hz), manufacturer and the selected algorithm used to correct GPS speed determination often varies. Therefore, it may not be suitable to generalize the findings of studies assessing the reliability and validity of individual GPS devices. Indeed, the findings of research performed on different GPS devices are generally inconsistent.

In relation to team-sport performance, a study performed by Macleod et al. (2009) compared a 1 Hz portable GPS (Spi Elite; GPSports, Canberra, Australia) against speed calculated from infra-red timing gates positioned at known distances (measured via a wheel trundle). Participants were required to complete a team-sports movement protocol (Macleod et al., 2007) and were assessed for speed and distance concurrently using each of the measurement methods. The speeds and distances related closely ($r > 0.9$) to 'criterion' measures, with paired t -tests also showing no systematic bias ($P > 0.05$). Total mean speed and straight line sprinting speed of the participants during the circuit demonstrated narrow 95% LoA, with random variation of $0 \text{ km}\cdot\text{h}^{-1}$ and $1.2 \text{ km}\cdot\text{h}^{-1}$, respectively. Interestingly, the only systematic error was found for sprint shuttle movement, demonstrating an overestimation of the GPS in comparison to timing gate methods (13.0 ± 1.9 c.f. $13.2 \pm 2.0 \text{ km}\cdot\text{h}^{-1}$). However, subsequent validation studies comparing timing gates and measured distances against GPS devices have not supported such a finding, particularly for sprinting performance.

In regards to the findings of Macleod and colleagues, it is important to consider the potential implications of the protocol adopted. Firstly, it would appear that the overestimation of the GPS for sprint performance appears related to the nature of the shuttle sprinting protocol. The adopted procedure involved turning 180° in order for the participant to propel the centre of mass (COM) in the opposite direction. As a result, the distance covered may be larger than assumed in order to correctly calculate speed using the simple division of displacement over time. Secondly, it is likely that the linear running trajectory of the participant will become perturbed over time, particularly under fatigue. Previous evidence supports this supposition since, even in conjunction with repeatable horizontal velocity during sprinting movements (CV = 1%), greater variability (CV = 9% to 34.6%) in COM displacement can be expected between consecutive sprinting trials (Hunter et al., 2004). Therefore, the subsequent

accumulation of lateral COM displacement over prolonged movement pathways is to be expected and may not be recognized using the timing gate method. The net result is an erroneous calculation in speed owing to an overestimation in the distance covered. The above issues also provide reasoning to disregard timing gate speed as a measure of criterion standard as suggested by Macleod et al. (2009), rather, a concurrent measure of the time taken to travel from a given point to another is recorded.

In light of the findings by Macleod and co-authors, subsequent analyses have sought to investigate team sport movements using similar protocols. For example, Coutts and Duffield (2010) reported upon the validity of 1 Hz GPS from two different manufacturers (GPSports & Catapult systems) to determine both distance and speed over a team sport running protocol (128.5 m \pm 0 m). Results suggested reasonable cross-comparison (< 5% CV) of all devices to the distance covered, which involved series of cutting movements and alterations in velocity (simulated team sport movement). For distance measured around the sport specific circuit, the newer SPI-Elite (126.1 \pm 5.6 m) and WI-SPI (129.1 \pm 8.2m) models (GPSports, Canberra, Australia) appeared to offer the most accurate measures. The authors discuss the potential for the newly integrated accelerometer (100 Hz) and the associated correction of the custom algorithm to provide a more valid interpretation of distance travelled. Accelerometers have been successfully applied in such a way, particularly for the prediction of energy expenditure in humans (Welk, 2002). Therefore, given the superior sampling rate offered by accelerometer devices, it is logical that their inclusion would enhance the interpretation of speed and distance. However, certain issues may preclude this outcome and are discussed within a later section of the current review.

Further notable findings from Coutts and Duffield (2010) include a significant relationship ($r = -0.40$ to -0.53) reported between timing gate speed and GPS peak speed for all devices. Similarly, Barbero-Alvarez et al. (2010) reported stronger relationships over 15 m ($r = 0.87$) and 30 m ($r = 0.94$) intervals between timing gate speed and 1 Hz GPS peak speed for sprinting movements. However, given the issues associated with assuming agreement based upon mere relationships between data sets (relative reliability) and the clear difference between peak and mean speed, such findings do not provide a suitable appraisal of the validity of the GPS for speed assessment. The limitations pertinent to relative reliability (see Atkinson & Nevill, 1998) are, in fact, well represented by Macleod et al. (2009) since a systematic overestimation was demonstrated in mean speed recorded by a 1 Hz GPS versus mean timing gate speed, however, a strong, significant correlation was also observed ($r = 0.99$ to 1.00) during shuttle protocols. The finding of a common bias, yet clear relationship, between timing gate speed and GPS speed is important to note since this may indicate the ability predict GPS values based upon linear regression analyses.

There is a continuing development in the sophistication of GPS technology which often includes the integration of an accelerometer within the GPS housing (Coutts & Duffield, 2010). With this inclusion comes an array of potential problems with speed determination. These issues are best represented by studies in which inter-unit variation have been investigated, wherein a substantial disparity (worst case of 20.2% CV for WI-SPI model during high intensity running) between singular GPS units of an identical construction has been shown (see Petersen et al., 2009; Coutts & Duffield, 2010; Duffield et al., 2010). However, concern regarding the adopted experimental procedures adopted between studies is warranted. For example, 'custom-built' harnesses are commonly used in order to facilitate the measurement of human movement whilst concurrently using multiple GPS units (Coutts &

Duffield, 2010; Duffield et al., 2010). In some cases, up to six or eight single units have been carried by one participant at one time (Coutts & Duffield, 2010; Gray et al., 2010). The manufacturer guidelines instruct that the GPS unit should be fitted to the upper-thoracic region, between the scapulae using the vest supplied with the GPS device, thus quantifying whole body movement. Fitting of the GPS unit outside of the manufacturers guidelines poses a variety of issues; firstly, accelerations will typically increase in magnitude when the accelerometer is positioned on lower body segments, such as at the leg and ankle, and will also differ due to deviation in lateral positioning (Mathie et al., 2004; Welk, 2002). It is important to note that accelerometry is commonly used to quantify segmental acceleration (i.e. limbs) recorded by an accelerometer, meticulously fitted to a pre-conceived position situated on the segment in question (Welk, 2002). Therefore, fixing multiple GPS monitors in a different position will influence the accelerometer recording owing to differences in body orientation between each position. While the use of a tri-axial accelerometer may be thought to negate these issues, accelerometers vary in sensitivity based upon the axis of measurement, often demonstrating reduced accuracy whilst measuring in a horizontal axis (Wong & Wong, 2008; Bouten et al., 1997). Consequently, given the likelihood of trunk inclinations during maximal sprinting, particularly if ‘crouch starts’ are employed, a disproportionate recording of acceleration should be expected.

A second issue pertaining to the use of an unspecified custom built harness is the proximity of the devices which may cause a multi-pathway effect in which the signal (antenna) from the GPS receiver is impeded or deflected by adjacent objects (Larsson, 2003). Based on the lack of knowledge regarding the harness utilised, it can be suggested that any concealment of the GPS antenna may reduce the clarity and resultant timing of radio signals, thus influencing the accuracy of the GPS integration. Thirdly, no study to date, has constructed a test re-test

protocol in which the GPS position on the unspecified harness is circulated or reversed. As a result, it cannot be assured that the claimed degree of disparity between GPS receivers is based upon an identical period of movement. With limited information regarding the customised harness utilised in previous studies, it is difficult to ascertain the degree of unit deviation that may have been caused, however, it is arguable that any unit placement differing from that provided by the manufacturer may influence the output from the accelerometer.

GPS models sampling at a higher rate (5 Hz) have been suggested to offer an improved assessment of both speed and distance during team based movement patterns. For example, Duffield et al. (2010) compared assessment of various speed and distance variables during court based movements using a 3D movement registration system (VICON; 100 Hz) and both a 5 Hz and 1 Hz GPS unit. Whilst certain measures, such as peak speed during fast (self-paced) running appeared to benefit from the use of a 5 Hz system (5 Hz = $0.2 \text{ km} \cdot \text{h}^{-1}$; 1 Hz = $0.7 \text{ km} \cdot \text{h}^{-1}$ discrepancy compared to criterion), such benefits remained unclear for measures of mean speed during random movement drills. Whilst it was clear that both GPS units underestimated the criterion 3D movement system, Duffield and colleagues failed to highlight the magnitude and consistency of such comparisons, owing to the adopted statistical approach. Using less preferable concurrent timing gate measures, other analyses have reported between 1% to 5% underestimations of sprinting speed or distance by both 1 Hz and 5 Hz GPS devices (Portas et al., 2010, 2007; Jennings et al., 2010; Petersen et al., 2009). Notwithstanding the lack of a true criterion measure within these analyses, the above studies have demonstrated improved accuracy of linear sprinting measurement with 5 Hz devices (1% bias) compared to 1 Hz devices (3% bias) (Portas et al., 2010).

Many types of TMA are now available for application to human movement research; however, comparison studies often show clear disparities between each method. For example, Edgecomb and Norton (2006) showed significant overestimation (8.7%) in a 1 Hz GPS compared to a computer based tracking (CBT) system for distance travelled at various unspecified speeds during 28 movement trials. More recently, Randers et al. (2010) compared movement patterns during a competitive soccer match comparing 1 Hz and 5 Hz GPS units with both semi-automated MCSs (Prozone) and manual TMA, as used by Mohr et al. (2003). The findings showed that, regardless of the intensity of movement, the agreement between distances measured by each method of analysis is subject to variation. This was reflected by significant differences in the total distance covered which ranged from 9.52 km (1 Hz GPS) to 10.83 km (MCS) in the worst case. However, comparisons between the 5 Hz GPS units (10.72 km) and the MCS showed no significant difference ($P > 0.05$) for distance covered, yet for both high and low intensity running the 5 Hz GPS (2.03 km and 3.08 km, respectively) showed lower distances travelled (MCS = 2.65 km and 3.63 km, respectively). Such results are particularly concerning given the intermittency in team sport movement patterns, comprising both high and low intensity patterns at regular intervals (Rampinini et al., 2009). Manual TMA systems, which remains popular in its application to the sports environment (Mohr et al., 2003), was also different from 5 Hz GPS measurement, reflected by a significant difference in total distance covered (9.51 km to 10.72 km). The differences found between manual TMA and 5 Hz GPS is likely the result of the criticisms previously outlined in which observer bias and inherent dependency upon estimated distances may cause error in the final calculations of outcome variables. In regards to MCS, errors may be sourced from loss of full computer automation during match play, thus necessitating human

intervention in order to maintain player tracking or from the drop in sampling rate apparent in some semi-automated systems (Carling et al., 2008).

On reflection, it would appear that no gold standard or criterion TMA measure currently exists for the capture of team sport performance (Carling, 2008). However, there is an ever increasing development of time motion equipment, for example, GPS monitors with improved sampling rate. Such developments may enable a more comprehensive quantification of movement demands by capturing additional positional information, thus leading to improved calculation of distance and speed. In terms of practicality, reliability, validity and data processing capacity, the current 5 Hz GPS models appear to offer the most robust measure of team sport movement patterns, particularly within low profile contexts such as youth sport competition.

2.18 Conclusion

Identifying talent or ‘higher ability’ amongst youth soccer and rugby league players, particularly in those progressing towards adult transitions, may rely upon the ability to recognize factors from both within and beyond the closed testing environment. Whilst there is a comprehensive body of literature highlighting the relative importance of certain physical attributes and ‘performance’ characteristics for identifying higher ability amongst youth sport players, quantifying such ability during match time has been difficult and remains a challenge for applied researchers. Such evidence may extend current concepts of what constitutes talent in youth soccer and rugby league players. Given the recent growth and availability of match-related measurement techniques and devices, it is possible and relevant to assess the long-

term development of match-related performance characteristics and their capacity to discern between lower and higher ability players. Furthermore, it is important to establish the limitations of novel measurement techniques, such as tests of sport-specific skill in rugby league, and the credibility of the contemporary technology, such as portable GPS devices, in order to identify the factors that are determinants of success.

Chapter 3: Validity and test re-test reliability of a Global Positioning System (GPS) and timing gates to assess sprint performance variables amongst youth rugby league players

3.1 Introduction

The use of Global Positioning System (GPS) technology to quantify the movement demands of elite youth team sports is becoming increasingly commonplace (Harley et al., 2010; Castagna, et al., 2009). The application of GPS devices for this purpose is preferable to alternative motion-analysis methods (see Sirotic et al., 2009; King et al., 2009; Sykes et al., 2009), due to its non-intrusive, economic, and time-effective use within team sports environments. However, the extent to which GPS devices can contribute to the development of practical and ‘sensitive’ field-based testing methods for the purpose of talent identification (Vaeyens et al., 2008) and accurately monitor the physical demands of competition in rugby league is not well understood. For example, recent reports have questioned the reliability and validity of GPS devices in comparison to criterion values of both distance (Petersen et al., 2009) and speed (Duffield et al., 2010). However, the generalization of such findings is limited, since the validity and reliability of a GPS device may be affected by both the manufacturer and the sampling rate, which often differ between studies (Duffield et al., 2010; Petersen et al., 2009). Indeed, the reliability of certain devices (GPSports, SPI-Pro, 5 Hz, Canberra, Australia) in measuring sprinting speed is yet to be evaluated. Sprinting performance is a key facet of adult rugby league match play (Gabbett et al., 2011a; Waldron et al., 2011a) and is associated with ‘higher ability’ in youth rugby league and soccer players in (Till et al., 2011; Gabbett, 2009). Therefore, the valid and reliable evaluation of sprinting activity of rugby league players in both training and match scenarios might support player preparation and selection.

Field-based tests of maximal sprint performance often involve using photocells or ‘timing gates’ in order to measure the time taken to travel between two points, set at a pre-determined distance. The reliability of the timing gate method has been favourably reported for assessment of 10 m sprinting, with a ‘standing start’ demonstrating 0.02 seconds (~1%) and 0.07 seconds (~1.3%) typical error (TE), respectively, enough to feasibly detect ‘worthwhile change’ in performance (Cronin & Templeton, 2008; Duthie et al., 2006). The ability to recognize small, yet practically relevant, changes is important since such tests are used, in part, to either select or deselect players onto talent development programmes (Reilly et al., 2000a). However, using timing gates to assess over-ground speed may often be logistically difficult to use within an applied sports environment (Portas et al., 2007) and are effected by adverse weather conditions and telemetry range. Owing to potential navigational errors, the timing gate method may also underestimate the true displacement of a participant over a given movement pathway, often utilised for validation procedures (Coutts & Duffield, 2010). As a result, such methods should not be considered as criterion surrogates, but rather a concurrent measure. Modern GPS devices also offer many additional measurement features, such as that of peak speed, which has demonstrated a strong relationship to sprinting time, measured using timing gates (Barbero-Alvarez et al., 2009; Coutts & Duffield, 2010). However, there are limited published data to quantify the level of absolute agreement between the two measures or to compare the test re-test reliability of both timing gates and GPS to assess singular linear sprinting speed. At present, the ability of the GPS (5 Hz) to distinguish between small, yet practically significant changes in short sprint performance remains unknown.

The relatively recent advancement in Micro electrical mechanical systems (MEMS) has also supported the integration of GPS technology with in-built tri-axial accelerometers (100 Hz).

The tri-axial accelerometer, housed within the current GPSports models (SPI-Pro; 5 Hz, Canberra, Australia), measures a composite vector magnitude produced by the user (expressed as g-force, the acceleration relative to free-fall). This is performed by recording the sum of accelerations measured in three separate orthogonal axes (anterioposterior [*x*], mediolateral [*y*] and vertical [*z*]). The accelerometer amplifies the displacement of a damped mass, attached to a supporting spring mechanism within the unit (Mathie et al., 2004). The advantages of advancements in MEMS technology may potentially enable researchers to quantify the magnitude of accelerative g-force experienced whilst reaching sprinting speeds, decelerating or changing direction. However, to date, the test re-test reliability of integrated accelerometry within current GPS devices is unknown, providing potential users with limited information regarding the sensitivity of current GPS technology to identify ‘proper’ accelerations. Therefore, the aims of the current study were to determine the validity and test re-test reliability of both a non-differential GPS device (5 Hz) and timing gates to measure selected variables of distance, speed, and acceleration during over-ground sprinting at various intervals.

3.2 Method

3.2.1 Participants

Nineteen elite youth male rugby league players (age: 14.7 ± 0.45 years; stature = 176.5 ± 6.5 cm; body mass = 72.8 ± 10.7 kg) and their parent/guardians gave consent to participate in the present study. The group comprised of 8 forwards, 7 adjustables and 4 outside backs (see King et al., 2009 for definitions). All participants were asked not to exercise on the day of testing and to follow their normal dietary guidelines. Each player was familiar with sprint and acceleration testing procedures and had previously worn the GPS equipment for training

purposes. Players were tested one week prior to the commencement of the forthcoming season. Ethical approval was granted by the Faculty of Applied Sciences Ethics Committee.

3.2.2 Design

Following appropriate familiarization, two maximal, linear sprint efforts were tested in one morning session. Selected variables of speed and acceleration were measured concurrently using both infra-red timing gates (Brower timing systems, Utah, USA) and portable GPS devices (GPSports, SPI-Pro, 5 Hz, Canberra, Australia). Test re-test reliability and the concurrent validity of both the timing gates and the GPS devices were subsequently carried out.

3.2.3 Procedure

One week prior to testing, participants completed a habituation protocol, comprising of three maximal sprint efforts at each sprint interval (10 m, 20 m & 30 m), separated by three minutes passive recovery. Suitable habituation to the testing protocol was established when no systematic learning effect was evident and when participants voluntarily indicated that the procedure for testing was understood. In order to prevent participants from decelerating prior to reaching the final timing gate (30 m), thus failing to reach or maintain true peak speed through 30 m, an additional coloured cone was placed at 35 m to which participants were instructed to consider as the finish point. Using the GPS equipment for verification, no indication of pre-emptive deceleration was demonstrated, with all participants consistently attaining peak speed post 30 m distance.

Testing took place on a still, calm day, across the centre of an open field, free from obstruction or adjacent buildings, thus preventing multipath effects (i.e. deflected GPS signal). All GPS units were simultaneously activated on the open ground and left for 15 minutes to ensure that an appropriate signal had been attained and to maintain an equal potential for drift error associated with the in-built accelerometer in each GPS unit (GPSports, 2010). The GPS units (size = 90 x 45 x 5 mm; mass = 86 g) sample at a rate of 5 Hz and are coupled with a tri-axial accelerometer sampling at 100 Hz. The typical number of available satellite signals was between 9 and 11 throughout the testing period and the horizontal DOP (HDOP) was recorded at 1.24 ± 0.3 . GPS vests (GPSports, Canberra, Australia) were tightly fitted to each participant in accordance with the manufacturer's guidelines. Vests were worn on top of a standard squad training shirt, thus placing the receiver approximately between the scapulae of the participant. Twenty minutes before exercise, players were taken for a structured warm-up led by the squad coach, consisting of moderate intensity movement, light dynamic stretching procedures and two maximal sprints.

The experimental protocol consisted of two maximal sprint efforts, starting from a standing position, over a flat, grass surface, separated by a period of three minutes of recovery. The brief testing period and close proximity of repeated trials was also intended to reduce the effect that transient changes in the dilution of precision (DOP) measurement may inflict on calculations of distance and speed. Indeed, the mean horizontal dilution of position (HDOP) was recorded at 1.2 ± 0.2 throughout the testing period, ensuring near optimal conditions for testing (Jennings et al., 2010). The correct sprinting course was marked with a pre-measured (tape measure) straight painted line, orthogonal to a light prevailing wind, upon which timing gates were positioned at 10 m intervals (0-30 m), as shown in figure 3.1. At each interval, timing gate height was set at 60 cm (see Cronin & Templeton, 2008). On both occasions,

participants were instructed to start sprinting from 30 cm behind the first timing gate, from their preferred foot, in order to prevent a pre-mature breaking of the infra-red beam. Participants were further instructed to begin sprinting from a static position in order to prevent pre-emptive backwards movement prior to accelerating (Frost et al., 2008). Split times were recorded at 10 m, 20 m and 30 m from a wireless receiver (Brower timing systems, Utah, USA) accurate to 0.01 s. All data were later downloaded to a personal computer using SPI EZY (V2.1, GPSports, Canberra, Australia) software and, subsequently, analyzed post hoc using Team AMS software (V2.1, GPSports, Canberra, Australia). Using Team AMS software, the initiation of a sprint was determined by a continuous increase in speed from below 0.1 km·h⁻¹ (Petersen et al., 2009).

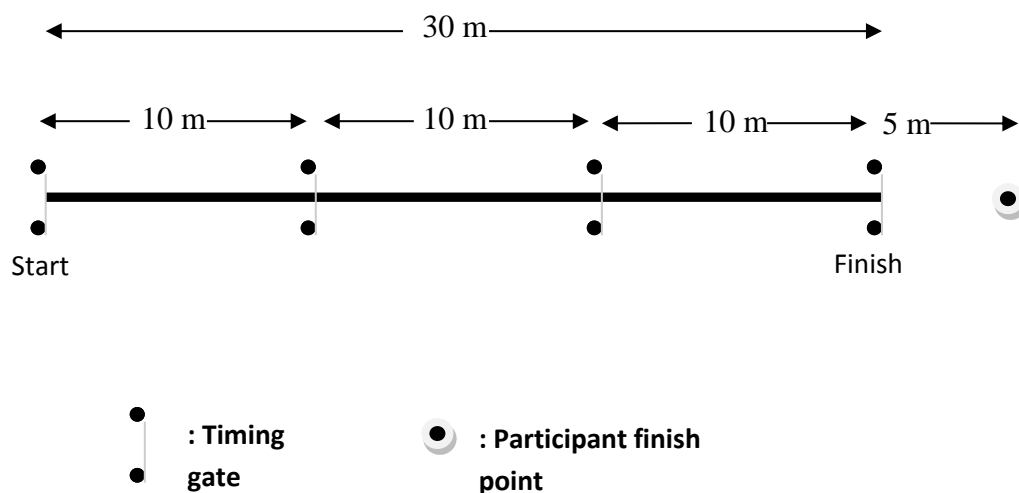


Figure 3.1. Schematic of procedure (not to scale).

3.2.4 Validity

Concurrent validity was determined by comparing mean speed ($\text{km}\cdot\text{h}^{-1}$) at 10 m, 20 m and 30 m and moving speed between 10 m and 20 m measured by the timing gates with values recorded using the GPS devices. The time interval recorded by the timing gate was used to truncate the speed data recorded by the GPS. Criterion validity was obtained by comparing distance at 10 m, 20 m and 30 m (quantified using a tape measure) to that recorded by the GPS devices. Speed derived from the timing gates was calculated by dividing the displacement of the participant (measured distance) by the time taken to travel the given distance.

3.2.5 Test-retest reliability

Test re-test reliability of both the timing gates and the GPS device to measure distance and mean speed at 10 m, 20 m & 30 m, 10 m to 20 m (moving) over the two repeated trials was assessed. Given the simultaneous capture of speed using both GPS devices and timing gates, it was also possible to compare the degree of test re-test reliability (within trial) of each method. Additional values of peak speed at 30 m, peak acceleration (g) and frequency of accelerations above 5.5 g over 10 m and 30 m were also assessed for test re-test reliability. Peak acceleration was defined as the largest positive acceleration recorded during the interval in question. The value of 5.5 g was used since this corresponds to the threshold pre-selected in the manufacturer's guidelines and a threshold value of 5 g has been used in previous studies assessing 'impacts' during match play in rugby union (Cunniffe et al., 2009). Furthermore, previous reports have demonstrated values of 5 g in a vertical axis during moderate intensity treadmill running, measured using an accelerometer fitted to the lower spinal region (Bhattacharya et al., 1980). As a result, a value of 5.5 g was deemed large

enough to detect significant accelerations whilst filtering extraneous noise from the accelerometer data.

3.2.6 Statistical analyses

Validity and reliability was assessed using 95% limits of agreement (95% LoA; Bland & Altman, 1986). Data were initially checked for normality of differences using the Shapiro-Wilk test ($P > 0.05$). Further checks for heteroscedasticity were carried out using Pearson product-moment correlation (r -value) to test for a relationship between the individual mean scores and the absolute differences. Ratio limits of agreement (95% Ratio LoA) were also reported (Bland & Altman, 1986) for all variables. Independent and paired samples t -tests were used to calculate differences (biases) between means of measurement methods (validity) or to compare measurements between trials (reliability), respectively. Significance was set at ($P < 0.05$) for all variables. In order to make comparisons to previous research, the coefficient of variation (CV; see method of Atkinson & Nevill (1998)) was also used to assess validity and reliability of performance measures. The strength of the CV ($< 10\%$) was quantified in accordance with Atkinson and Nevill (1998). The use of varied statistical approaches for assessment of validity and reliability was adopted in order to provide means for a “global comparison amongst future researchers” (Atkinson & Nevill, 1998, pg. 220). Data were reported as mean and standard deviation (SD) throughout. SPSS (Version 19) software was used for all statistical analyses.

3.3 Results

3.3.1 Validity

Results from 95% LoA showed a systematic underestimation ($P < 0.05$) of the GPS against that of the timing gates for all variables of distance (Table 3.1). Heteroscedasticity was present for all measures of distance ($r = -1$; $P < 0.05$) and 10 m moving speed ($r = 0.73$; $P < 0.05$). Heteroscedastic results were inevitable for variables of distance in the present study given the clear systematic bias and the stability ($SD = 0$) of the criterion measure of distance. For all results demonstrating heteroscedasticity, 95% ratio LoA showed systematic biases ranging from (1.05 to 1.12) and random errors ranging from (1.11 to 1.29), translating to a 39% total error in the worst case (10 m sprint distance; 95% LoA = $1.10 \times / \div 1.29$). However, using the CV method, these same results were reported as reliable, with results consistently below 10% (CV = 4.8 to 8.1%).

For all speed variables, there were significant differences ($P < 0.05$) between timing gate and GPS values (Table 3.1). Mean biases ranged from 2.01 to 2.19 $\text{km} \cdot \text{h}^{-1}$, with random errors of 2.18 to 3.62 $\text{km} \cdot \text{h}^{-1}$ which, in one instance, equated to a potential error of 5.67 $\text{km} \cdot \text{h}^{-1}$ (10 m sprint; $2.05 \pm 3.62 \text{ km} \cdot \text{h}^{-1}$). CV's ranging from 5.68 to 9.81% were evident for all speed measures. Each statistical method demonstrated a trend for an improvement in the level of congruence between estimated speed of the timing gates and the GPS as the distance of the sprints from a standing start increased. However, the closest level of agreement for both speed (95% LoA = $2.03 \pm 2.85 \text{ km} \cdot \text{h}^{-1}$; 95% Ratio LoA = $1.08 \times / \div 1.12$) and distance (95% LoA = $0.47 \pm 1.34 \text{ m}$; 95% Ratio LOA = $1.05 \times / \div 1.15$) were found during the moving 10 m sprint.

Table 3.1. Validity of measured distance and timing gate speed against GPS measurements

	Measured distance/timing gate mean \pm SD	GPS measure mean \pm SD (m)	CV (%)	95% LoA	95% Ratio LoA
Distance (m)					
10 m sprint	10 \pm 0	9.07 \pm 1.11*	8.06	0.92 \pm 2.18	1.10 \times/\div 1.29
20 m sprint	20 \pm 0	17.91 \pm 1.66*	8.09	2.09 \pm 3.25	1.12 \times/\div 1.21
30 m sprint	30 \pm 0	27.98 \pm 1.45*	5.00	2.01 \pm 2.84	1.07 \times/\div 1.11
Moving 10 m	10 \pm 0	9.52 \pm 0.68*	4.81	0.47 \pm 1.34	1.05 \times/\div 1.15
Speed (km·h⁻¹)					
10 m sprint	16.52 \pm 1.19	14.46 \pm 1.94*	9.81	2.05 \pm 3.62	1.15 \times/\div 1.30
20 m sprint	20.48 \pm 1.15	18.28 \pm 1.66*	8.54	2.19 \pm 3.34	1.12 \times/\div 1.20
30 m sprint	22.73 \pm 1.23	20.72 \pm 1.43*	6.61	2.01 \pm 2.18	1.09 \times/\div 1.11
Moving 10 m	27.02 \pm 1.20	24.98 \pm 1.97*	5.68	2.03 \pm 2.85	1.08 \times/\div 1.12

Note (for all tables): CV = Coefficient of variation; 95% LoA = 95 % Limits of agreement; 95% Ratio LoA= 95% Ratio Limits of agreement. * = significantly different ($P < 0.05$) from measured distance or timing gate speed. Moving 10 m = speed between timing gate 2 and 3 during the 30 m sprint. Speed data are reported as mean speed unless otherwise stated.

3.3.2 Test re-test reliability

GPS measurements of speed, distance and acceleration, demonstrated no significant differences ($P > 0.05$) for any of the measured variables between the first and second trial (Table 3.2). As presented in table 3.2, using the 95% LoA method, mean differences between trials ranged from 0.04 to 0.23 m for distance and from 0 to 0.09 km·h⁻¹ for speed. Measurement of peak speed demonstrated the highest level of reliability (95% LoA = -0.00 \pm 0.8 km·h⁻¹; 95% Ratio LoA = 1.00 \times/\div 1.03; CV = 0.78%).

Table 3.2. Reliability of sprinting distance, speed and acceleration measured by the GPS

	Test 1	Test 2			
	GPS	GPS			
	measure	measure	CV	95% LoA	95% Ratio LoA
	mean \pm SD	mean \pm SD	(%)		
<i>Distance (m)</i>					
10 m sprint	9.08 \pm 1.16	9.04 \pm 0.93	1.99	0.04 \pm 0.72	1.00 \times/\div 1.08
20 m sprint	17.90 \pm 1.66	18.14 \pm 1.68	2.06	-0.23 \pm 1.42	0.98 \times/\div 1.08
30 m sprint	27.98 \pm 1.45	28.06 \pm 1.44	1.84	-0.08 \pm 1.75	0.99 \times/\div 1.06
Moving 10 m	9.52 \pm 0.68	9.58 \pm 0.61	2.30	-0.06 \pm 1.13	0.99 \times/\div 1.13
<i>Speed (km·h⁻¹)</i>					
10 m sprint	14.46 \pm 1.94	14.41 \pm 1.74	2.06	0.05 \pm 1.05	1.00 \times/\div 1.07
20 m sprint	18.28 \pm 1.66	18.34 \pm 1.74	1.92	-0.05 \pm 1.17	0.99 \times/\div 1.06
30 m sprint	20.72 \pm 1.43	20.81 \pm 1.43	2.02	-0.09 \pm 0.84	0.99 \times/\div 1.07
Moving 10 m	24.98 \pm 1.97	25.00 \pm 1.87	1.62	-0.02 \pm 1.35	0.00 \times/\div 1.05
Overall peak speed	29.48 \pm 1.56	29.47 \pm 1.48	0.78	-0.00 \pm 0.8	1.00 \times/\div 1.03

Table 3.3 shows the results from speed assessment using timing gates. Small mean biases (-0.01 to -0.14 km·h⁻¹) for all sprint intervals and random errors between test 1 and 2 ranging from 0.56 to 1.64 km·h⁻¹ were demonstrated. Using the CV method, all sprint intervals showed high levels of reliability (1 to 1.54%). Largest errors were found in the moving 10 m sprint.

As shown in Table 3.4, accelerations ranging from 5.1 to 12.52 g were found over sprint intervals of both 10 and 30 m. Table 3.4 shows the average values found for 10 m peak acceleration (7.32 \pm 2.25 to 7.03 \pm 1.82 g) and 30 m peak acceleration (8.28 \pm 1.81 to 8.33 \pm 1.56 g) both of which displayed a CV of over 5%. While no significant differences were

found between test 1 and 2 for any of the measured values, random errors ranging from 2.3 to 1.73 g were recorded for 10 and 30 m sprints, respectively. The frequency of accelerations > 5.5g for the 30 m sprint demonstrated the largest degree of parity between trials (CV = 14.12%) equating to a potential 93% total error.

Table 3.3. Reliability of sprinting speed using timing gates

	Test 1	Test 2			
	Timing gate speed \pm SD ($\text{km}\cdot\text{h}^{-1}$)	Timing gate speed mean \pm SD ($\text{km}\cdot\text{h}^{-1}$)	CV (%)	95% LoA	95% Ratio LoA
<i>Speed ($\text{km}\cdot\text{h}^{-1}$)</i>					
10 m sprint	16.52 \pm 1.19	16.53 \pm 1.18	1.13	-0.01 \pm 0.54	0.99 \times/\div 1.04
20 m sprint	20.48 \pm 1.15	20.6 \pm 0.9	1.00	-0.12 \pm 1.09	0.99 \times/\div 1.05
30 m sprint	22.73 \pm 1.23	22.87 \pm 1.03	1.35	-0.14 \pm 0.94	0.99 \times/\div 1.04
Moving 10 m	27.02 \pm 1.20	27.15 \pm 1.47	1.54	-0.12 \pm 1.64	0.99 \times/\div 1.06

Table 3.4. Peak accelerations and frequency of accelerations using integrated accelerometry

	Test 1	Test 2			
	GPS/ accelerometer mean \pm SD	GPS/ accelerometer mean \pm SD	CV (%)	95% LoA	95% Ratio LoA
<i>Peak Acceleration (g)</i>					
10 m sprint	7.32 \pm 2.25	7.03 \pm 1.82	5.01	0.28 \pm 2.30	1.02 \times/\div 1.30
30 m sprint	8.28 \pm 1.81	8.33 \pm 1.56	5.16	-0.05 \pm 1.73	0.99 \times/\div 1.22
<i>Frequency (> 5.5 g)</i>					
10 m sprint	6.84 \pm 2.98	6.63 \pm 3.11	4.69	0.21 \pm 1.68	1.04 \times/\div 1.24
30 m sprint	14.26 \pm 5.24	13.26 \pm 4.62	14.12	1.00 \pm 5.43	1.02 \times/\div 1.91

3.4 Discussion

3.4.1 Validity

The initial aim of the current study was to report on both the concurrent and criterion validity of a 5 Hz GPS to measure speed and distance, respectively, during linear sprinting activity. In accordance with previous research (Duffield et al., 2010; Petersen et al., 2009; Gray et al., 2010; Jennings et al., 2010), the results of the current analysis demonstrate the systematic underestimation of the GPS in terms of both distance and speed at 10 m, 20 m, 30 m and 10 m moving speed. Moreover, previous research has reported similar underestimations of linear distance, ranging between 6% to 20%, whilst using identical SPI-Pro (5 Hz) GPS devices (Petersen et al., 2009). In the present study, application of the 95% ratio term revealed a total error reaching 39% ($1.10 \times/\div 1.29$; CV = 8.06%) for 10 m distance, equating to a 45% total error for 10 m speed validity ($1.15 \times/\div 1.30$; CV = 9.81%). Consequently, the degree of validity between timing gate speed and measured distances in comparison to GPS measurements cannot be favourably reported for short sprinting performance.

Since all GPS measures of distance systematically under-reported that of the criterion measure, gaining a true notion of speed using the current GPS model appears problematic. GPS speed calculation partly relies upon known changes in position (displacement) coupled with accurate quantification of radio signal time delay between orbiting satellites and receivers (Witte & Wilson, 2008). Therefore, issues with the valid calculation of distance may confound a resultant calculated value of speed. Of course, it is acknowledged that this estimation of speed is also supplemented by a Doppler shift calculation and the use of an additional algorithm (Larsson, 2003). Nevertheless, the above issue regarding the apparent poor criterion validity of GPS distance measures, and the inevitable impact upon calculation of speed, remains pertinent to future users of GPS devices for assessment sprint performance.

Given previous reports, showing the potential for 5 Hz GPS models of different manufacturers to underestimate true criterion speed by 0.1 to 0.8 m·s⁻¹ (0.36 to 2.88 km·h⁻¹; Duffield et al., 2010), coupled with the current findings, it may be suggested that the timing gate method offers a more valid measure of speed. Whilst this may be true, the continual development of increasingly sophisticated technology, varied in specification, often prevents researchers reaching an agreement on the exact degree of error, since it is clear that both manufacturer (Petersen et al., 2009) and sampling rate (Duffield et al., 2010; Petersen et al., 2009) affect the level of reliability and validity found in GPS devices. For example, Townshend et al. (2008) demonstrated a high level of validity against that of timing gates set at measured distances (mean error ~ 0.01 s at various distances and speeds; $r = 0.999$) for over-ground movement on a linear course. However, a commercially available GPS was utilised for the study, sampling at 1 Hz and was fitted to the head of a participant. Such differences are a clear example of potential methodological issues preventing direct comparisons between investigations. As such, researchers should remain aware that the current disparity between methods of speed assessment may vary dependent upon the GPS model used.

A previous method comparison between timing gates and GPS at similar rates of locomotion, over singular linear pathways, reported CV of 1% using a 1 Hz GPS model (Portas et al., 2007). Such evaluations differ to the results presented herein, where a 5 Hz model was used (CV range = 5.68 to 9.81%). Unfortunately, the reasons for the disparity between the previous and current findings remain difficult to interpret since a comprehensive account of the study by Portas and colleagues is unavailable. A further study has also reported contrasting results whilst using a 1 Hz GPS to measure linear speed, finding significant overestimations of mean speed against speed estimated from timing gates (Macloed et al.,

2009). However, Macleod and colleagues adopted the use of a shuttle protocol where measurement of displacement may be severely compromised by the multiple 180° turns required to complete the course. As a result, participants are likely to have covered a greater distance than expected in the same time period, thus equating to a faster running speed. Whilst it is acknowledged that the differences between previous investigations and the current analysis may be the result of changes in sampling rate (i.e. 1 Hz to 5 Hz), it is possible that the methodological oversights mentioned above may also account for the previous overestimations.

The notable trend for an improved validity of measurement (i.e. become closer in agreement) as the distance of the sprint increased and, in absolute terms, the speed of the sprint increased, is supported by the previous findings (Petersen et al., 2009; Jennings et al., 2010) where the agreement between criterion and GPS calculations of distance improved as the larger distances were covered. Petersen and colleagues reported agreements of $5.4 \pm 2\%$, $4.2 \pm 1.5\%$ and $2.9 \pm 1.1\%$ (SEM) for sprints exceeding $18 \text{ km}\cdot\text{h}^{-1}$ at increasing distances of 20 m, 30 m and 40 m, respectively, whilst using a GPS receiver identical to the devices used within the present study. The reason for such a trend in results appears to be linked to the 5 Hz sampling rate of the SPI-Pro models (GPSports). While the ability to sample locomotive movement at a frequency equivalent to five instances per second improves upon the capabilities of previous 1 Hz models, the level of sophistication remains deficient for assessing intense periods of sprint performance. This deficiency is exacerbated over smaller distances since rapid changes in linear movement offer less opportunity for positional measures to be recorded.

Interestingly, the 10 m moving speed demonstrated a higher level of validity for both distance (95% Ratio LoA = $1.05 \times/\div 1.15$; CV = 4.85%) and speed (95% Ratio LoA = $1.08 \times/\div 1.12$; CV = 5.68%) than any other measure, even though this was the shortest distance assessed. Removing the accelerative period from the sampled performance, where participants are required to generate forward locomotion from a static position appears to result in a reduced impact upon the GPS sampling frequency. As with sprints measured over larger distances, the moving 10 m sprint involves a more continuous gait cycle and, therefore less alteration in speed. Consequently, as sprint intervals decrease in distance, less time is available for the GPS receiver to sample vast changes in speed, thus influencing the accuracy of measurement over shorter distances. Based on the above reasoning, it is plausible to suggest that the inclusion of a 20 m linear moving speed calculation in future investigations would again improve the validity of the measure. Such suggestions are encouraging for the use of the current GPS model in team sports scenarios, where rolling sprints are commonly observed (Carling et al., 2008). Similarly, shorter sprint intervals (i.e. 5 m accelerations) may yield a larger magnitude of error. These current findings are noteworthy since previous research has failed to directly test for such a possibility.

3.4.2 Test re-test reliability

The present study is the first to compare the test re-test reliability of both the GPS and the timing gates for selected variables of sprint performance. Previous investigations using dual beam timing gates to assess sprint speed have found typical errors of 1% (Duthie et al., 2006), 1.3% (Cronin & Templeton, 2008) and 1.9% over a 10 m distance. Further investigations have demonstrated CV values of 2% and 1.9% over 10 and 20 m, respectively (Moir et al., 2004), which are comparable to those values observed in the present study (CV =

1% to 1.54%), The reliability was strongest for 10 m and 20 m sprint speed ($CV = 1\%$ to 1.13%), which may be attributed to the participants' familiarity with sprint intervals of this magnitude during seasonal conditioning and competition (see Chapter 7).

Similarly, the reliability of the GPS over all variables ranged from 0.78% to 2.3% (CV), with the most reliable measure being peak speed over 30 m ($CV = 0.78$; $95\% \text{ LoA} = -0.00 \pm 0.8$; $95\% \text{ Ratio LoA} = 1.00 \times/\div 1.03$). The higher reliability between 10 m and 20 m in timing gates compared to GPS may be a consequence of the increased opportunity for participants to deviate away from the linear pathway, thus influencing the reliability of this distance over repeated trials. Previous evidence may support this supposition since, even in conjunction with repeatable horizontal velocity during sprinting movements ($CV = 1\%$), greater variability ($CV = 9\%$ to 34.6%) in centre of mass (COM) displacement can be expected between trials (Hunter et al., 2004). The subsequent accumulation of lateral COM displacement over prolonged movement pathways is, therefore, to be expected which may be recognized using GPS devices but not whilst using the timing gate method.

There is currently no published data investigating the absolute test re-test reliability of peak speed using GPS over repeated trials, yet, this value is often strongly related to speed from timing gates in validation trials (see Barbero-Alvarez et al., 2009; Coutts & Duffield, 2010). True peak speed of each participant was, in fact, never attained during the present analysis. This finding is attributed to the required maximal 30 m distance used within the current experimental protocol, which is within the suggested necessary range required (50 m to 60 m) to elicit maximal velocity (Young et al., 2001). Due to this fact, the ability to yield such reliable results over repeated trials may be aided since participants can more easily reach a

peak speed that is within their maximum physical capacity, requiring only a single 0.2 second sample of speed (i.e. 5 Hz). It is possible that sampling peak speed attained over a larger period may have produced less reliable results. Nevertheless, a total error of $0.8 \text{ km}\cdot\text{h}^{-1}$ offers sports practitioners, wishing to monitor changes in sprint performance, a useful variable to consider, since an error of such seemingly negligible magnitude would allow for detection of minor changes in performance. Indeed, such findings should encourage the utilisation of peak speed and related outcome variables over 10 m to 30 m distances, such as; peak acceleration ($\Delta \text{ velocity} / \Delta \text{ time}$), force ($\text{mass} \times \text{acceleration}$) and peak power ($\text{force} \times \text{distance} / \text{time}$) (see Chapter 6). This has particular relevance for measurements of closed physical performance that are often implicated in the process of talent identification since it supports the use of the GPS as a practical and reliable field-based tool to monitor various aspects of sprint performance.

The levels of reliability reported for timing gate assessments in the present study suggest this to be a preferable method for the assessment of over-ground sprinting. As a result, the apparent inferiority of the current GPS reliability should be viewed accordingly. It is suggested that researchers wishing to monitor systematic changes in sprint performance, should first carefully consider the degree of acceptable measurement error that can be tolerated in order to detect practically significant changes in performance. Atkinson and Nevill (1998) refer to this as creating ‘analytical goals’ (p. 221), prior to selecting the method of measurement (in this case a 5 Hz GPS model or timing gates). The current data may, indeed, support both methods of speed measurement for reliable assessment of short sprinting bouts, dependent upon what degree of measurement error is tolerable in order to detect an adequate change in performance.

In order to provide an example for the above suggestions; research has documented the ability to differentiate between 10 m sprint performance of first and second grade rugby league players, reporting statistically significant differences equivalent to 0.1 seconds (Gabbett, 2009). On average, participants within the current study sprinted a 10 m distance at a mean speed of approximately $14.4 \text{ km}\cdot\text{h}^{-1}$. The degree of mean bias present whilst using the GPS device to measure 10 m sprinting was $0.05 \text{ km}\cdot\text{h}^{-1}$ and the level of random variation was $1.05 \text{ km}\cdot\text{h}^{-1}$ (total error = $1.1 \text{ km}\cdot\text{h}^{-1}$). If the current GPS devices were to be used, hypothetically, to reliably test for changes of the magnitude required to differentiate between playing ability, as in the study of Gabbett (2009), it is possible that a typical performer from the present sample (true mean speed of $14.4 \text{ km}\cdot\text{h}^{-1}$) may be subjected to a worst case erroneous underestimation of $13.35 \text{ km}\cdot\text{h}^{-1}$ mean speed (i.e. minus $1.1 \text{ km}\cdot\text{h}^{-1}$). However, a 0.1 second difference for a typical performer running at $14.4 \text{ km}\cdot\text{h}^{-1}$ over 10 m (as above) is equivalent to a change in mean speed of $0.56 \text{ km}\cdot\text{h}^{-1}$, translating to an actual speed of $13.84 \text{ km}\cdot\text{h}^{-1}$. Therefore, in this instance, the current GPS devices would not provide an adequate means of differentiation between first and second grade players, since the degree of error is larger than required to detect such a change. Interestingly, if the same process is carried out using the 95% limits of agreement for timing gate speed over 10 m, the degree of total error found ($0.55 \text{ km}\cdot\text{h}^{-1}$) may marginally tolerate such an application. Practitioners engaged in talent identification procedures should consider these results in line with their desired threshold of what constitutes higher or lower ability.

Given that differences shown in the above example are not uncommon within an elite sport science environment and are further supported by the large effect size (0.85) reported by

Gabbett (2009), it is reasonable to suggest that the current GPS models should be used for purposes requiring less sensitive calculations of changes in speed, particularly over short intense periods of sprinting activity. Consequently, sports practitioners attempting to use GPS devices for similar purposes to the present study should use the current data in conjunction with the potential change in performance. For example, based upon the present results from the 95% ratio LoA, to detect a 5% change (relatively small) in 10 m sprint performance using the current GPS model, a sample size of 10 may be used (Atkinson et al., 1999). Such a sample size is easily attainable for practical uses. To detect larger changes (i.e. 10%) which may be the case for practical purposes, a lesser sample would also be sufficient.

An additional benefit of using current GPS models is the potential ability to quantify *g*-force using an accelerometer integrated within the GPS device. Perhaps as a result of the recent development in GPS-accelerometry integration, little is known regarding the reliability of this device to measure acceleration during sporting movement patterns, such as sprinting. Selecting two distinct categories (peak acceleration and frequency of acceleration > 5.5 *g*) for analysis over 10 m and 30 m, the current study demonstrated the potential for large variations in the frequency of accelerations, particularly over 30 m intervals (CV = 14.12%; 95% LoA = 1.00 ± 5.43 *g*). In a recent study by Cunniffe et al. (2009), total frequency of accelerations (> 5 *g*) were calculated as 798 and 1294 (38.4% difference) for backs and forwards, respectively. The large differences found in the current study between repeated trials provide a poor forecast for researchers attempting to differentiate between positional groups during competitive team sports, where accelerating and decelerating movements increase in prominence. Based upon the degree of difference required to distinguish between positional groups, as found by Cunniffe et al. (2009), it can be expected that the potential 91% random

error currently found over 30 m sprints, would not tolerate such uses and are likely beyond the degree of acceptable error for most measurements.

In addition to previous analyses, it should be recognized that ‘impacts’ (see Cunniffe et al., 2009) per se are not truly measured by the accelerometer, rather, accelerations are measured that, when associated with a mass, may cause a forceful impact. The current data showed that accelerations up to 12.52 g were recorded during simple linear sprinting activity, which is much larger than previously reported for running activities (see Bhattacharya, 1980). Therefore, in order to discriminate between accelerations due to an external mass (i.e. due to a tackle), or merely due to self-propelled movement, may require the addition of a well-structured classification system, thus supplementing accelerometer readings with a visual indication of the actions taking place. For example, Kelly et al. (2012) attempted to cross-validate the recognition of collisions using GPS-accelerometry against manual video-based observations. Kelly et al. (2012) reported ~95% recall rate (i.e. true positives / (true positive + false negatives) using the GPS-accelerometer. However, Kelly and colleagues failed to show the reliability of manual observations, which is unfortunate since these are the basis of the validation. Furthermore, whilst the model proposed by Kelly et al. (2012) may be used to detect the occurrence of a collision, it does not identify the magnitude of deceleration. Further validation trials would be useful for future research, since, at present, the reliability of the integrated accelerometer appears questionable and the effects of this upon validity are unknown.

The errors recorded for peak acceleration over 10 and 30 m intervals (CV = 5.01 to 5.16%) are larger than previously reported (CV = 3.6%) for test re-test trials using a hip-fitted tri-axial accelerometer to quantify the magnitude of accelerations during over-ground walking

(Moe-Nilssen, 1998). However, based on the theory of analytical goals previously discussed, it is unclear whether this level of reliability would be required for performance differences during match play. Potential users should consider this prior to deciding upon the purpose of GPS-accelerometer use. Nevertheless, based on arbitrary values of $CV < 10\%$, the current analysis demonstrates a reliable tool for measuring the magnitude of accelerations. This was particularly noteworthy over 10 m intervals, where less error is apparent, possibly due to the limited opportunity for noise accumulation.

It is important to note that accelerometry is commonly used to quantify segmental acceleration (i.e. limbs) recorded by an accelerometer, meticulously fitted to a pre-conceived position situated on the segment in question (Welk, 2002). Attaching an accelerometer to the lower spine of participants, Bhattacharya (1980) reported vertical g -force recordings of up to 6 g during treadmill running. Attempts to compare the current data to previous studies using isolated accelerometry, however, should be discouraged since GPS-based accelerometers provide a measure of ‘whole body acceleration’. When positioned on the thoracic spine (via a nylon vest), the accuracy of the accelerometer is severely jeopardised as a result of many confounding factors, each of which should be considered by researchers. Firstly, accelerometer measurements may be influenced by changes in body orientation and, while the use of a tri-axial accelerometer may be thought to negate these issues, accelerometers vary in sensitivity based upon the axis of measurement, often demonstrating reduced accuracy whilst measuring in a horizontal axis (Wong & Wong, 2008; Bouten et al., 1997). Consequently, given the likelihood of trunk inclinations during maximal sprinting, a disproportionate recording of acceleration could be expected when attempting to quantify whole body acceleration. Secondly, the magnitude of the signal obtained by the accelerometer is affected by the stability of the mounting on the surface of the body and can

be sensitive to seemingly negligible changes in the integrity of underlying support, such as the influence of soft tissue artefact (Sinclair et al., 2010). The GPS vest supplied by the manufacturer does not support the accelerometer (or at least the GPS housing) in the manner often specified for accelerometry purposes (Welk, 2002). Subsequently, the resultant signal received by the accelerometer may be largely influenced by external noise (i.e. acceleration due to mechanical resonance), therefore causing large measurement errors, even over short sprint intervals.

It was important for the current study to use the GPS models in the exact manner advocated by the manufacturer, replicating use in an applied sport science environment. As such, no instruction to calibrate the accelerometer is suggested. It is our contention that, as with most measures of human performance, such steps should be included by the manufacturer in order to minimise the effects of error derived from technical inadequacies. In addition, while the procedure adopted within the present study was designed to negate the impact of the inherent ‘error drift’ that, according to the manufacturer, occurs in the accelerometer module (GPSports, 2010), it is possible that the accumulation of heat generated within the housed unit had influenced the accuracy of the measurements (Ang et al., 2004). Due to proprietary information, the magnitude and time course of the error is unknown and, therefore, may have influenced the accelerometer measurement during the second repeated trial. Once again, it is difficult to rule out the potential noise caused by such factors, however, it is unlikely that this fully accounts for the errors demonstrated. Therefore, it is important to gather a greater understanding of such errors since, when used for practical purposes, it can be expected that these errors may account for some of the variance in measurement reliability.

Assessments of reliability using GPS often adopt a protocol involving a concurrent measurement of distance and speed (e.g. Duffield et al., 2010). In one case, six units have been simultaneously attached to the participant (Coutts & Duffield, 2010) using an unspecified shoulder mounted harness. While such methods enable an inter-unit comparison (i.e. between-devices), there are potential flaws with this procedure. Firstly, accelerations will typically increase in magnitude when the accelerometer is positioned on lower body segments, such as at the leg and ankle, and will also differ due to deviation in lateral positioning (Mathie et al., 2004; Welk, 2002). With limited information regarding the customised harness utilised in previous studies, it is difficult to ascertain the degree of unit deviation caused, however, any unit placement differing from that provided by the manufacturer may severely influence the output from the accelerometer. Secondly, researchers should be aware of ‘multi-pathway’ effects, where the signal from the GPS receiver is impeded or deflected by adjacent objects. Any concealment of the GPS antenna owing to the proximity of neighbouring GPS devices may reduce the clarity and resultant timing of radio signals, thus influencing the accuracy of the GPS device.

3.5 Conclusion

Based on the current evidence, it is suggested that the GPS devices (5 Hz, SPI-Pro) may be used to quantify small, yet practically significant, changes in sprint performance, particularly for the measurement of peak speed in young rugby league players. However, caution should be exercised when attempting to compare such results to calculations derived from the timing gate method, which is underestimated by the 5 Hz GPS device. Regardless of such disparities, there remains a clear use for GPS measures of sprint performance during training scenarios where the timing gate method is often logistically impractical. However, the

continued use of timing gates is advocated for assessment of sprint performance due to the superior reliability observed. Measurements of acceleration derived from the integrated accelerometer produced questionable results, particularly for the frequency of accelerations. It is recommended that researchers refrain from using the current accelerometers for sensitive experimental purposes. However, further research into the validity of integrated accelerometry is warranted.

Chapter 4: Predicting 30 m timing gate speed from a 5 Hz Global Positioning System (GPS) device

4.1 Introduction

Among youth team sport athletes, over-ground sprinting ability is often assessed using infra-red timing gates, which have been shown to provide reliable data over short (10 m to 20 m) distances (Cronin & Templeton, 2008; Duthie et al., 2006, Moir et al., 2004). For measurements undertaken in the field, such methods appear to have received global acceptance, with research commonly using sprinting performance to identify higher and lower ability players (Gabbett, 2009). However, given the random nature of training drills in an applied team sport context, it has been suggested that the use of timing gates to assess speed provides an unsuitable and cumbersome measure (Portas et al., 2007). In addition, timing gates are limited by battery life, memory, telemetry range and, when used outdoors, are affected by environmental surroundings, such as wet or forceful wind conditions.

The application of portable global positioning systems (GPS) to training environments is currently growing in popularity (Hill-Haas et al., 2009) and, due to logistical practicalities, could provide an alternative measure of linear running speed. However, whilst a case has been made that GPS, in particular the 5 Hz Spi-Pro model (GPSports, Canberra, Australia), can measure sprint distances reliably (Portas et al., 2010; Petersen et al., 2009), the accuracy of GPS-determined running speed has not been thoroughly established. Indeed, recent research has shown 5 Hz GPS models to underestimate both distance and speed compared to criterion measures, particularly during short (≤ 30 m) sprinting movements (Duffield et al., 2010; Petersen et al., 2009). However, owing to the limited statistical approaches of previous analyses, the degree of both systematic and random error between timing gate speed and 5 Hz GPS speed has not been addressed (see Atkinson and Nevill, 1998). As such, the use of GPS devices to monitor linear over-ground speed is currently limited. Accordingly, the purpose of this study was to (i) evaluate the concurrent validity between a 5 Hz GPS and timing gates for

measuring mean speed over 30 m, and (ii) examine whether regression analysis could yield an accurate model to predict over-ground speed from GPS values.

4.2 Methods

4.2.1 Participants

Following ethical approval from the Faculty of Applied Health Sciences Research Ethics Committee, 60 elite male soccer and rugby league participants (age: 14.2 ± 0.67 years; stature: 171.6 ± 9.8 cm; body mass: 66.1 ± 12.9 kg) and their parents/guardians provided written informed consent to participate in the present study.

4.2.2 Design

Participants were required to individually perform one 30 m maximal, over-ground sprint from standing and were measured for mean speed concurrently using both an infra-red timing system (Brower timing systems, Utah, USA) and a portable GPS device (5 Hz; GPSports, Canberra, Australia).

4.2.3 Procedure

Participants initially undertook a warm-up period consisting of moderate intensity running, a standardised dynamic stretching routine and two maximal sprints. Two timing gates were set at opposing ends of a pre-measured painted 30 m line, across the centre of a flat open grass-covered field. Both sets of timing gates were set at a height of 60 cm (Cronin & Templeton, 2008). A coloured cone was placed at 35 m (5 m beyond the final timing gate) which

participants were instructed to consider as the finish point, thus preventing premature deceleration. While precise environmental conditions were not recorded, the surface of the field was dry and only a light cross-wind was apparent during the testing session. All the GPS units (5 Hz; GPSports, Canberra, Australia) were simultaneously activated on the open ground and allowed 15 minutes to ensure that an appropriate satellite signal had been attained. The mean horizontal dilution of position (HDOP) was recorded at 1.3 ± 0.3 with available satellites ranging between 9 and 12 during the session. Data collection took place free from obstruction or adjacent buildings, thus preventing multipath effects (i.e. deflected GPS signal). The GPS units (size = 90 x 45 x 5 mm; mass = 86 g) sample at a rate of 5 Hz and are coupled with a 6 g tri-axial accelerometer sampling at 100 Hz. GPS vests were appropriately fitted to each participant in accordance with the manufacturer's guidelines, with the receiver positioned approximately between the scapulae.

Each participant was instructed to start sprinting from 30 cm behind the first timing gate (off their preferred foot), in order to prevent an unwanted breaking of the infra-red beam. Sprint times were recorded using a wireless receiver (Brower timing systems, Utah, USA) accurate to 0.01 s. All data were later downloaded to a personal computer using SPI EZY (V2.1, GPSports, Canberra, Australia) software and, subsequently, analyzed using Team AMS software (V2.1, GPSports, Canberra, Australia). A speed ranging between 0-0.1 km·h⁻¹ was used to determine that the participant was motionless at the point of initiation. The sprint was determined by the maintenance or increase in speed (i.e. no decrease) from the specified motionless range (see above) until the 30 m distance had been reached (Petersen et al., 2009).

4.2.4 Statistical Analyses

Descriptive statistics (means \pm SD) were calculated for mean timing gate speed and both mean and peak GPS speed. Speed derived from the timing gates was calculated by dividing the displacement of the participant (30 m) by the time taken to travel the given distance. Mean GPS speed was calculated using Team AMS software and was truncated using the recorded splits taken from the timing gates. Peak speed was defined as the highest single recording of movement over the 30 m distance. The concurrent validity between GPS mean speed and timing gate speed was assessed via a paired *t*-test (to quantify the bias between the mean scores of the two methods) and followed up using the 95% limits of agreement (95% LoA) (Bland & Altman, 1986) technique to quantify the within-subjects variation (random error). Checks on the normality and the homoscedasticity of the errors were performed using the Shapiro-Wilk and Pearson's product-moment coefficient, respectively. The bivariate relationship between timing gate mean speed and both GPS mean and peak speed was quantified using Pearson's *r* value. Two linear regression analyses (using an enter method) were performed with timing gate mean speed as the dependent variable in each case. Separately, GPS mean speed and GPS mean speed plus peak speed were used as the independent (predictor) variables. Equations for both models were formulated along with the typical regression statistics (R^2 and SEE) to assess the accuracy of each. This process generates a separate (cross-validation) regression equation for one half of the sample that is applied to the other half and seeks to establish that there is minimal shrinkage in the R^2 value relative to the cross-validation model. This being the case, the full predictive model can be presented. Significance was set at $P < 0.05$ throughout and all data were analyzed using SPSS (version 19).

4.3 Results

As demonstrated in Table 4.1, the GPS device systematically underestimated ($P < 0.05$) mean speed compared to the timing gates, with 95% of the differences ranging between 0.56 and 3.36 $\text{km}\cdot\text{h}^{-1}$. However, there was also a strong, significant relationship between these measures ($r = 0.85$, $P < 0.005$), and likewise for mean timing gate speed and peak GPS speed ($r = 0.91$, $P < 0.005$).

Table 4.1. Concurrent validity of GPS mean speed and timing gate mean speed

Timing gate mean speed ($\text{km}\cdot\text{h}^{-1}$)	GPS mean speed ($\text{km}\cdot\text{h}^{-1}$)	95% LoA	Pearson's r -value
22.8 ± 1.2^a	20.8 ± 1.35	1.96 ± 1.4	0.85

Note: a = significantly higher ($P < 0.05$) than GPS mean speed

The regression analysis based upon the cross-validation sample (Table 4.2) revealed that both mean and peak GPS speed explained 81.9% (adjusted $R^2 = 0.819$) of the variance in the dependent variable, yielding the equation; Predicted timing gate speed = $4.363 - (0.001 \times \text{mean GPS speed}) + (0.619 \times \text{GPS peak speed})$.

Table 4.2. Overall parameters of the cross-validation prediction model using both GPS mean and peak speed ($\text{km}\cdot\text{h}^{-1}$) to estimate timing gate speed ($\text{km}\cdot\text{h}^{-1}$) ($n = 30$).

Predictor Variables	Unstandardized Coefficients	Standardized Coefficients		
	B	Standard Error	Beta	t -value
Model 1				
(constant)	4.363	1.576		2.769 ^b
GPS Mean Speed ($\text{km}\cdot\text{h}^{-1}$)	-0.001	0.117	-0.001	-0.10
GPS Peak Speed ($\text{km}\cdot\text{h}^{-1}$)	0.619	0.098	0.913	0.6135 ^a

Note: Adjusted $R^2 = 0.819$; $a = P < 0.05$, $b = P < 0.001$.

Table 4.3. Cross-validation of predicted and observed timing gate speed ($\text{km}\cdot\text{h}^{-1}$) ($n = 30$)

Predicted timing gate mean speed ($\text{km}\cdot\text{h}^{-1}$)	Timing gate mean speed ($\text{km}\cdot\text{h}^{-1}$)	95% LoA	Adjusted R^2
23.2 ± 1.3	23.1 ± 1	-0.06 ± 1.15	0.803

Note: Predicted timing gate speed = $4.363 - (0.001 \times \text{mean GPS speed}) + (0.619 \times \text{GPS peak speed})$

The cross-validation analysis (Table 4.3) revealed a non-significant bias ($P > 0.05$) between the predicted and observed timing gate speed and 95% LoA and an adjusted R^2 (80.3%) that represented a shrinkage of 1.6% relative to the cross-validation model (81.9%, Table 4.2).

The overall regression analysis (Table 4.4) revealed that peak GPS speed explained a greater proportion of the variance in the dependent variable than mean GPS speed, but together both significantly contributed to the prediction model (adjusted $R^2 = 0.840$, SEE = $0.49 \text{ km}\cdot\text{h}^{-1}$).

The equation was: mean timing gate speed = $2.869 + (0.246 \times \text{mean GPS speed}) + (0.497 \times \text{GPS peak speed})$. For 95% of the sample, the accuracy of the multiple regression model was $0.98 \text{ km}\cdot\text{h}^{-1}$. The equation without peak GPS speed (Table 4.5) was: mean timing gate speed = $6.598 + (0.778 \times \text{mean GPS speed})$.

Table 4.4. Overall parameters of the prediction model using both GPS mean and peak speed ($\text{km}\cdot\text{h}^{-1}$) to estimate timing gate speed ($\text{km}\cdot\text{h}^{-1}$) ($n = 60$).

Predictor Variables	Unstandardized Coefficients		Standardized Coefficients	<i>t</i> -value
	B	Standard Error	Beta	
Model 1				
(Constant)	2.907	1.203		2.417 ^a
GPS Peak Speed ($\text{km}\cdot\text{h}^{-1}$)	0.668	0.04	0.909	16.61 ^c
Model 2				
(constant)	2.869	1.146		2.503 ^a
GPS Peak Speed ($\text{km}\cdot\text{h}^{-1}$)	0.497	0.076	0.677	6.574 ^c
GPS Mean Speed ($\text{km}\cdot\text{h}^{-1}$)	0.246	0.094	0.27	2.619 ^b

Note: Adjusted $R^2 = 0.823$ for model 1 and 0.840 for model 2. $a = P < 0.05$, $b = P < 0.01$, $c = P < 0.001$.

Table 4.5. Overall parameters of the prediction model using GPS mean speed ($\text{km}\cdot\text{h}^{-1}$) to estimate timing gate speed ($\text{km}\cdot\text{h}^{-1}$) ($n = 60$).

Predictor Variable	Unstandardized Coefficients		Standardized Coefficients	<i>t</i> -value
	B	Standard Error	Beta	
Model 1				
(Constant)	6.598	1.309		5.309 ^a
GPS Mean Speed ($\text{km}\cdot\text{h}^{-1}$)	0.778	0.063	0.853	12.440 ^a

Note: Adjusted $R^2 = 0.723$, $SEE = 0.65 \text{ km}\cdot\text{h}^{-1}$. $a = P < 0.001$.

4.4 Discussion

Using a sample of elite youth team sport players, the present study has demonstrated an underestimation of $1.96 \text{ km}\cdot\text{h}^{-1}$ mean over-ground timing gate speed by a 5 Hz GPS device. Moreover, in no case did the GPS device over-estimate mean timing gate speed. Consistent with previous suggestions, such a finding is likely to be due to the relatively low sampling capability of the 5 Hz GPS model during intense periods of linear human movement over short distances (Duffield et al., 2010; Jennings et al., 2010; Petersen et al., 2009). Indeed, over a 26 m rectangular course, Duffield et al. (2010) have reported a comparable mean underestimation of 5 Hz GPS speed compared to speed measured via criterion 3D camera systems ($0.5 \text{ m}\cdot\text{s}^{-1} \sim 1.8 \text{ km}\cdot\text{h}^{-1}$). Nevertheless, given the predictive accuracy of the regression models developed on the current data (from 0.98 to $1.27 \text{ km}\cdot\text{h}^{-1}$ for 95% of the sample), such bias on behalf of the 5 Hz GPS device does not undermine its validity and/or efficacy as a highly practical field tool and its use to evaluate 30 m sprint performance should be encouraged. Furthermore, on the basis of the cross-validation analysis, one can be confident of the generalizability of the above model and, subsequently, its ability to predict accurately timing gate speed.

The 5 Hz GPS would be particularly useful in an environment where it is preferable to assess multiple players simultaneously, thus significantly reducing the testing period. Furthermore, both GPS mean speed and peak speed are measures that can be simply calculated using Team AMS software and also provide a reliable indication of such measurements over various running speeds and distances (Petersen et al., 2009). The merits of applying the current regression model to correct GPS mean speed will, however, depend largely upon the context of its use, since the associated degree of variability ($0.98 \text{ km}\cdot\text{h}^{-1}$) would prevent its use for more sensitive purposes. In such cases, researchers should consider the degree of sensitivity required to detect changes in performance prior to utilising the current model to measure over-ground sprinting over 30 m. For example, using the assessment of over-ground running speed (20 m to 40 m), previous research has demonstrated age related differences within youth rugby league players equating to $3.4 \text{ km}\cdot\text{h}^{-1}$. The current GPS model and associated regression model could be used to detect a change of such a magnitude (i.e. the error is less than the systematic change). It should also be noted that practitioners wishing to use the current prediction models to evaluate sprint performance should consider doing so under similar conditions to those of the present study. That is, using testing grounds with no adjacent buildings, optimal satellite geometry (HDOP of 1 - 2) and satellite availability (minimum of four), since these factors will affect the GPS signalling (Jennings et al., 2009). Meeting these minimum requirements will facilitate the utility of the proposed prediction equations.

A further application of the current model also exists for research that uses GPS to investigate sprinting activity in team sport (McLellan et al., 2011, 2010; Gabbett, 2010; Randers et al., 2010; Coutts et al., 2009). The above examples, have made the delineation between ‘high

intensity' and 'sprinting' or 'very high intensity running' categories based upon previous data collected via timing gates or alternative manual chronometry methods (see Deutsh et al., 1998; Bangsbo et al., 1991; Mclean, 1992; Docherty et al., 1988; Reilly & Thomas, 1976). When used in this manner, it is likely that studies using GPS devices to quantify sprinting activity in team sports will underestimate the actual movement characteristics. Based upon the evidence provided within the present study, GPS devices could be used to record sprinting speed. Alternatively, the proposed regression equation (Model 1, Table 4.4) can be used to extrapolate equivalent GPS sprinting speed zones from those proposed using over-ground chronometry. For instance, a sprinting category used within a recent study was 23 km·h⁻¹ (Coutts et al., 2009), which, based on a re-arrangement of the equation from Model 2, translates to a GPS speed of $21.08 \pm 1.27 \text{ km}\cdot\text{h}^{-1}$ $[(23 - 6.598) / 0.778 = 21.08]$.

4.5 Conclusion

The present study has demonstrated the systematic underestimation of timing gate mean speed by a 5 Hz GPS device. Although the present results should not deter practitioners or researchers from using timing gates to assess sprint performance over 30 m intervals, it is suggested that the current regression models support the use of a 5 Hz GPS device as an alternative measure of over-ground speed. Such an application may be particularly useful within a team sport environment where often large samples of players are assessed under open conditions. Practitioners should also remain cognisant of limitations whilst using GPS devices to monitor vast changes in velocity over brief intervals (Duffield et al., 2010; Jennings et al., 2010; Petersen et al., 2009), which may preclude the use of correction models at sprint distances less than 30 m in length. Perhaps the most beneficial use of the proposed model, however, would be its capacity to correct the speed zones used for the assessment of

sprint performance during competition. In order to extend the use of regression models for similar applied purposes, further investigations should sought to examine the relationship between timing gates and GPS speed at a variety of intensities and distances

**Chapter 5: The reliability of tests for sport-specific motor skill amongst elite youth
rugby league players**

5.1 Introduction

In rugby league, tests of sport-specific skill have been used to differentiate between higher and lower playing standards in both adult (Gabbett et al., 2011b; Gabbett et al., 2007) and junior players (Gabbett et al., 2010). The employed tests are typically technique (process) rather than outcome based, involving subjective assessments relating to the quality of the performed skill, performed within simulated playing scenarios. Such tests meet the ‘open’ nature of skill within the context of team sport, requiring players to execute the correct technique in a realistic playing environment (Ali, 2011). For example, studies have employed the use of highly qualified coaching staff (Australian Rugby League Level 3 coaching accreditation) to devise standard criteria for the assessment of fundamental game-related skills such as tackling, catching and receiving the ball during sport-specific conditioning practices or rugby league matches (Gabbett et al., 2008a; Gabbett, et al., 2007). The proficiency of players has been subsequently based upon a Likert scale rating provided by an observer (Gabbett et al., 2010; Gabbett et al., 2008a; Gabbett, et al., 2007). Such tests have grown in popularity since the assessment of technical skills performed within an open environment may offer a more realistic playing scenario in comparison to the closed skill testing often utilised in skill test batteries (Ali, 2011).

While process-driven measures ostensibly reveal a deeper dimension of technical ability (Williams & Reilly, 2000), such tests remain scientifically questionable owing to the subjective nature of their scoring or assessment, even amongst experienced and appropriately qualified coaches (i.e. Level 3 Rugby League Coaching Qualification). Although Gabbett et al. (2007) demonstrated a seemingly reliable testing procedure for the assessment of tackling an opponent and passing or receiving of the ball ($ICC = 0.85$ to 0.98 and $CV = 5.1$ to 5.3%),

the degree of attainable reliability for observers without qualification or experience in the sport has been reported less favourably (CV = 4.7 to 8.7%; Gabbett et al., 2008a). Indeed, assessments of this type lack procedural consistency between studies and often overlook the potential for perceptual (systematic) differences between experienced or non-experienced observers. The higher degree of experience and level of coaching qualification is broadly considered to support the credibility of the coach to discern between correctly or incorrectly executed sport-specific skills (Ste-Marie, 1999). Therefore, the recognition of, and differentiation between, systematic bias and random error are important for research of this type (see Atkinson & Nevill, 1998). However, assessment of *relative* reliability (instead of *absolute* reliability) or statistics that fail to quantify systematic bias and random error have been commonly applied to skill tests (Gabbett et al., 2008a). Furthermore, the use of certain statistical procedures, such as the CV or, indeed, traditional parametric analyses such as 95% limits of agreement (LoA), to test for agreement between ordinal data sets (Likert scales), is also questionable (Cooper et al., 2007).

Parametric statistical tests are carried out on the assumption that the dependent variables follow a normal distribution (Atkinson & Nevill, 1998). However, ordinal data often follow a non-normal distribution and, accordingly, should be treated with non-parametric analyses (Cooper et al., 2007; Bland & Altman, 1999). Further considerations, such as the tolerable degree of error when using a 1 to 5 Likert scale (Gabbett et al., 2007), should be made in the context of previous findings. For example, previous research using Likert scales to discern between lower and higher ability players in the skills of catching, passing and tackling in rugby league players, has demonstrated ‘significant’ differences equating to 0.5 and 0.6 on the Likert scale in adults (Gabbett et al., 2007) or 0.75 (mean difference over various skills) in junior players (Gabbett et al., 2010). Using a non-parametric reliability analysis on such

ordinal data sets will quantify the repeatability of assessments ranging from zero to five (without decimals). Therefore, notwithstanding the erroneous presentation of unattainable mean scores in previous studies, it is clear that to recognize such minor differences below the score of 1, the observer must achieve a ‘perfect’ agreement (i.e. less than 1). As a result, any error in subjective assessment would be intolerable. In this context, the *a-priori* analytical goal of any researcher attempting to administer such tests in order to discern between playing standards in rugby league players, should be to achieve a high proportion of perfect agreement. For this reason, and those highlighted above, the credibility of subjectively scored tests in rugby league motor skill tests remains to be established, thus limiting the application of such tests for talent identification purposes. Accordingly, the aims of the current study were to investigate: (i) the intra-observer reliability of a non-qualified observer (‘novice’), and (ii) the inter-observer reliability of the three observers (two qualified ‘experts’ and one novice observer) in the assessment of catching, passing and tackling (stages 1 and 2) ability in elite adolescent rugby league players.

5.2 Methods

5.2.1 Participants

Twenty elite youth male rugby league players (8 forwards, 6 backs & 6 adjustables; King, et al., 2009) contracted to a professional club in the North West of England volunteered to participate in the study (age: 14.7 ± 0.5 years; body mass: 72.8 ± 10.7 kg; stature: 176.5 ± 6.5 cm). All participants were asked not to exercise on the day of testing and to follow their normal dietary guidelines. Each player and the coaches were familiar with the testing protocols (see Procedures section) via their usual training practices and had 7.2 ± 1.2 years of

formal playing experience, defined as a minimum of one training session and weekend match with a rugby league club. The two expert observers in the current study were Level 3 (RFL) qualified coaches employed by the club and had 10 to 15 years of coaching experience. Consent was obtained from the players and their parents/guardians and approval for the study was granted by the Faculty of Applied Sciences Ethics Committee.

5.2.2 Skill simulation procedure

All testing procedures took place outdoors on a grass training pitch under dry, mild weather conditions, over a period of one-to-two hours on the same day. Using examples from previous research (Gabbett et al., 2010; Gabbett et al., 2008a), a simulated sport-specific match scenario was devised and implemented (as shown in Figure 5.1). The skills of passing, tackling and catching were selected since they represent fundamental game skills in rugby league that are performed by all players (see Sirotic et al., 2009). The players performed a ‘warm-up’ (in groups of three) led by the club coach, consisting of moderate intensity running and upper and lower body dynamic stretching exercises, immediately prior to the skills tests.

The players were randomly selected to complete the test as either one of two attacking players who retained possession of the ball or a defensive player. Set within a 10 x 10 m grid, attacking players (ball carriers) were required to advance from one side of the grid to the other and complete one pass each before being tackled by the defending player. After one cycle of this protocol, the players were instructed to wait for a brief recovery period (remaining on their feet) at the opposite end of the grid before repeating the drill in the

opposite direction. The test was designed to obligate catching, passing and tackling from both the player's left and right hand sides. If an action was performed that was deemed to be outside of the skills being assessed, such as an incorrect sequence of passing, the players were allowed to re-start the trial. To avoid such issues, demonstrations from qualified coaches (Level 3 Rugby League Coaching Qualification, UK) were performed prior to the testing procedures in order to enhance players' understanding of the test and to provide them with a reference for the required match-like intensity. The practice was continued until the coaches notified the researcher that they had completed their assessment (see criteria in Table 5.1), which lasted between four and six repetitions for each trial (~ 2 min). Once the observer had provided a score out of five for each of the three skill components, the players were required to exchange roles, with one player per drill under assessment. Once the first group of players had completed their rotation as the tackler, the next group of three commenced an identical testing procedure. A camera (Canon MV 700i, 50 Hz, Japan) was set up approximately at eye level of the coaches in a static position at a distance of 15 m from one end of the grid and used to film all proceedings (Figure 5.1). This was later used by the novice observer for technical skill assessments (see following sections).

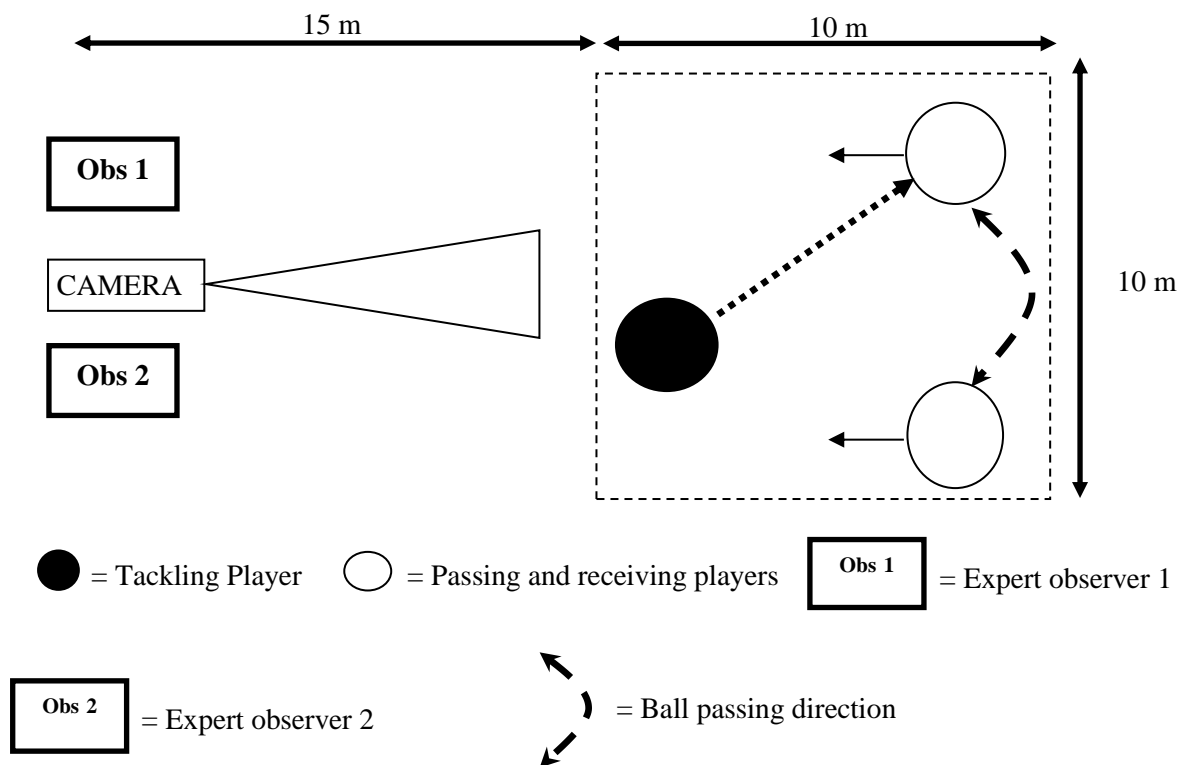


Figure 5.1. Rugby league tackling, passing and catching protocol (based on Gabbett et al., 2010). *Note:* the above diagram shows the protocol in one direction. Players performed the test in both directions. The novice observer was filming the training practice.

5.2.3 Skill assessment procedure

The skills of the players were assessed by two expert coaches with 10 and 15 years of coaching experience, respectively, using set criteria (Table 5.1) previously established by Gabbett et al. (2007). The aim for the observer was to rate the players (in real-time) on their overall proficiency in each skill using a Likert scale ranging from one to five, with five representing an optimal score and one representing the lowest score possible. The expert and novice observers were provided with the assessment criteria one week prior to the testing, and subsequently given explicit instruction to refer to the criteria during the testing

procedures. For consistency, the expert observers were positioned equi-distant either side of the camera, enabling a similar perspective of the players. Each observer was not made aware of the other's scores. The inclusion of a novice observer (having watched rugby league for the previous two seasons but no coaching qualification) enabled a comparison with the expert assessors. To be consistent with the analyses of the experts, the novice observer was required to analyze, continuously, the video footage (without slowing or re-watching the footage) of the players' performances using the set criteria, albeit post-event. In order to evaluate the consistency of his subjective assessments (intra-observer reliability), he was required to repeat this task a week later. Following the recommendation of Gabbett et al. (2007), two stages of assessment (approach, Stage 1; execution, Stage 2) were included for each skill yielding two scores per skill performed.

Table 5.1. Standard criteria for the assessment of tackling, passing and catching techniques.

Skill		Criteria
Catching	Stage 1	Stage 2
	Hands up	Catch the ball
	Fingers up	Holding the ‘body’ of the ball
	Palms out	Prepared to carry the ball or execute a pass
	Call for the pass	Minimal breaking of the natural stride
	Take pass early	
Passing	Stage 1	Stage 2
	Pendulum action	Receiver able to catch the ball
	Look where passing	Receiver able to maintain stride
	Single movement	
	Flat and behind	
	Ahead of receiver	
Tackling	Stage 1	Stage 2
	Low body position	‘Turtle’ player
	Arms ready	Hold defensive shape
	Head behind/to one side	Point to remaining player being marked
	Contact with shoulder	
	Wrap arms around waist	
	Drive with legs	
	Pull with arms	
	Maintain grip until on ground	

Note: to ‘turtle’ is to hold the opposing player immobile on the floor in a supine position

5.2.4 Statistical analyses

The distributions of the six skill elements (approach and execution of catching, passing and tackling) were initially checked for normality using the Shapiro-Wilk test and where violations were observed ($P < 0.05$), non-parametric Kruskal-Wallis tests were applied to test for differences between observers (expert 1, expert 2 and the novice). Post-hoc Mann Whitney-U tests were used for pairwise comparisons between each of the observers. The presence of bias between the test and re-test trials of the novice observer was checked via a

median-sign test. Owing to the multiple (six) comparisons made between each different observer (novice, expert 1 and expert 2), the Benjamini Hochberg False Discovery Rate (FDR) technique was applied to control for the potential increase in the type I error rate. The technique involves, firstly, ranking the P -values ($p_{(1)} \leq p_{(2)} \leq \dots \leq p_{(k)}$) obtained from a series of multiple comparison tests performed under a shared hypothesis, from smallest to largest (six comparisons between each observing pair in the current case). The formula $k\alpha/n$ is used to derive the FDR where; k = rank, α = alpha level (0.05), n = number of tests. Beginning with the largest (step-up), each original P -value is compared to the FDR (i.e. compare $p_{(k)}$ to $k\alpha/n$). At the point at which $p_{(k)} \leq k\alpha/n$, the null hypothesis was rejected and every value thereafter (Benjamini & Hochberg, 1995). The degree of random variation between or within observers was evaluated using the non-parametric technique advocated by Cooper et al. (2007). This technique involved calculating the percentage of agreement and associated 95% confidence intervals (CIs) between or within observers inside a ‘practically important’ reference value (Nevill et al., 2001). As established above, a reference value of perfect agreement (zero difference between observations) was deemed as ‘practically important’ for each type of skill assessed. A secondary reference value of ± 1 (a difference of one in either direction) was also set in order to demonstrate the portion of agreement between observers in the presence of the smallest possible error that can be made on the 1-5 Likert scale. Additionally, the coefficient of variation (CV) was calculated to enable comparisons with the findings of previous research.

5.3 Results

Table 5.2. Median and inter-quartile range for the subjective scoring assessments of expert and novice observers.

		Median	25th Percentile	75th Percentile
Catching Stage 1	Expert 1	5	4	5
	Expert 2	5	4	5
	Novice	5	4	5
Catching Stage 2	Expert 1	5	4	5
	Expert 2	5	4	5
	Novice	4	3	4
Passing Stage 1	Expert 1	4	4	5
	Expert 2	5	4	5
	Novice	4	3	4
Passing Stage 2	Expert 1	5	4	5
	Expert 2	5	4	5
	Novice	4	4	5
Tackling Stage 1	Expert 1	4	4	4
	Expert 2	4	4	5
	Novice	4	3	5
Tackling Stage 2	Expert 1	4	3	5
	Expert 2	4	4	5
	Novice	4	3	4

Based upon the data presented in Table 5.2, the Kruskal-Wallis tests identified significant observer effects on stage 1 ($X^2_{(2)} = 10.5, P = 0.005$) and 2 ($X^2_{(2)} = 9.7, P = 0.008$) of catching performance, and stage 1 of passing ($X^2_{(2)} = 5.8, P = 0.046$). Post-hoc comparisons revealed higher scores ($P < 0.05$) recorded by both experts than the novice observer for each stage of catching, and the first stage of passing (Table 5.3). Likewise, there was a significant observer effect on stage 2 of tackling ($X^2_{(2)} = 5.76, P = 0.049$) which was attributable to the score of expert 2 being higher than that of the novice ($P < 0.05$). Based upon the analytical goal of a ‘perfect agreement’, further analysis showed that the degree of variation between the expert

coaches and the novice was as low as 30%, and no better than 65%. The CV statistics for the same comparisons ranged between 7.9% and 14.3%, and included only four values below 10% (Table 5.3).

Systematic bias was not present between expert observers and whilst there were no instances of 100% perfect agreement between them, it ranged from 75% to 90% in all passing and catching skills. However, for the tackling skills the agreement was notably lowered (60% to 65%). Nonetheless, all the CVs for the three skills were below 10% (1.6% to 8.1%). For the novice, intra-observer analysis revealed no overall difference ($P > 0.05$) between any scores, and the levels of agreement in the range 70% to 85%. CVs were below the 10% threshold for all scores, ranging from 3.4% to 6.0%.

Based upon the less stringent analytical goal of plus or minus '1' on the Likert scale, better agreement was achieved for all comparisons. For example, Table 5.3 shows that between expert observers and the intra-reliability of the novice observer, agreement was 100% in all but one comparison (tackling stage 1 for expert 1 to expert 2). Expert versus novice agreement remained sub-optimal, though was as high as 95% for most of the scores.

Table 5.3. Comparisons of the inter- and intra-observer reliability of expert and novice rugby league practitioners.

Inter-observer	<i>P</i> -value	Perfect Agreement		Plus or Minus 1		CV (%)
		PA (%)	95% CIs (%)	PA ± 1 (%)	95% CIs (%)	
Expert 1 to Expert 2						
Catching Stage 1	0.323	80	44.6 to 100	100	83.8 to 100	3.6
Catching Stage 2	0.560	85	47 to 100	100	83.8 to 100	2.8
Passing Stage 1	0.520	75	44.2 to 99.6	100	83.8 to 100	4.2
Passing Stage 2	1.000	90	49.4 to 100	100	83.8 to 100	1.6
Tackling Stage 1	0.324	60	34.9 to 81.8	100	83.8 to 100	7.8
Tackling Stage 2	0.188	65	37.3 to 87.8	95	76.3 to 99.1	8.1
Expert 1 to Novice						
Catching Stage 1	0.002*	45	27.4 to 64.2	95	76.3 to 99.1	11.0
Catching Stage 2	0.002*	45	27.4 to 64.2	95	76.3 to 99.1	11.0
Passing Stage 1	0.005*	50	29.9 to 70	90	69.8 to 97.2	11.5
Passing Stage 2	0.185	65	37.3 to 87.8	95	76.3 to 99.1	7.9
Tackling Stage 1	0.786	50	29.9 to 70	95	76.3 to 99.1	11.6
Tackling Stage 2	0.518	65	37.3 to 87.8	95	76.3 to 99.1	8.12
Expert 2 to Novice						
Catching Stage 1	0.003*	30	19.5 to 46.8	90	69.8 to 97.2	14.3
Catching Stage 2	0.004*	35	22.2 to 52.5	90	69.8 to 97.2	13.7
Passing Stage 1	0.023*	50	29.9 to 70	85	63.9 to 94.7	12.5
Passing Stage 2	0.185	55	32.4 to 75.9	95	76.3 to 99.1	9.5
Tackling Stage 1	0.230	60	34.9 to 81.8	95	76.3 to 99.1	9.0
Tackling Stage 2	0.033*	50	29.9 to 70	90	69.8 to 97.2	11.5
Intra-observer						
Novice trial 1 to 2						
Catching Stage 1	1.000	80	44.6 to 100	100	83.8 to 100	4.6
Catching Stage 2	1.000	85	47 to 100	100	83.8 to 100	3.8
Passing Stage 1	0.219	70	39.8 to 93.7	100	83.8 to 100	6.0
Passing Stage 2	1.000	85	47 to 100	100	83.8 to 100	3.8
Tackling Stage 1	0.625	80	44.6 to 100	100	83.8 to 100	4.4
Tackling Stage 2	0.250	85	47 to 100	100	83.8 to 100	3.4

Note: * = significantly larger for the expert observer based on pairwise comparisons ($n = 20$). Benjamini Hochberg adjusted alpha levels.

5.4 Discussion

It was the analytical goal of the present study to obtain ‘perfect agreement’ between expert observers in order to meet the requirements outlined in previous research (i.e. a difference of less than ‘1’ on the Likert scale). In no case was 100% perfect agreement obtained between the expert observers and, given the width of the 95% confidence intervals (approximately 44% to 100% for catching and passing skills), it is likely that some talented players could be incorrectly appraised using such tests, which may contribute to the coaches’ misinterpretation of their playing ability. That is, in the skills of passing and catching, the ‘population’ agreement between experts could be as high as 100% or low as 44%, rendering the potential for disagreement and performance misinterpretation to be as high as 56%. Importantly, for the same data, the CV ranged from 2.8% to 8.1% which is less than the magnitude often deemed as ‘reliable’ (< 10%; Atkinson & Nevill, 1998) and, similar to previous research in rugby league (Gabbett et al., 2007). In the context of talent identification, it is typically expert coaches who are responsible for discerning between players showing signs of higher or lower ability. Therefore, given that reports in rugby league have failed to establish the inter-observer reliability between expert observers via the correct statistical approach, the general application of subjective rating systems across different expert users has to be questioned.

The current results should be interpreted on behalf of the broader rugby league community in accordance with the tolerable degree of error. That is, those charged with identifying talented players based, in part, upon the construct of sport-specific skill measured in such a way are required to consider what degree of error is acceptable. For example, if a tolerance of plus or minus one on a scale of one to five is deemed satisfactory, then the current data would indicate a much better level of agreement between expert observers than if zero difference reference value was adopted. However, in the context of talent identification, this parity

between observers does not support the worthiness of the test for correctly interpreting skilled performance in higher ability players. Rather, the probability of misinterpreting (falling within plus or minus one) the quality of sport-specific skill is reinforced.

The limited agreement between experts was also exacerbated within both stages of tackling. The reliability of the assessment of tackling was the poorest between experts, with a perfect agreement as low as 50%. Such poor agreement may relate to the open nature of the skill in which a simulated collision between two participants induces a less predictable environment in which to base judgements of technical performance. Indeed, previous analyses have assessed such skills within the open match environment (Gabbett et al., 2007), in which a stability of the set criteria, such as the upper and lower body position, cannot be expected. Moreover, it could be argued that the set criteria will vary according to the context in which the tackle is performed, such as side-on and chasing tackles. In addition, research has shown that only 17% of tackles in rugby league are performed in a one-on-one scenario, with players often tackling in conjunction with other team-mates (King et al., 2010). Such findings support our previous assertion regarding the situational inconsistencies during match time, adding further complication to the assessment of tackling technique. Whilst these suggestions detract from the potential reliability of tackling analysis, the intention of previous researchers to enhance the ecological validity of skill testing should be recognized. Given the current findings and the general disparity between both experts, it remains unclear exactly what criteria expert observers are basing their judgements on. Indeed, it would be useful to evaluate the intra-observer reliability of expert observers' ratings, with and without the use of the set criteria.

The ratings of the experts were found to be systematically higher ($P < 0.05$) than the novice observer in the skills of catching (all stages) and passing stage 1. Such results fundamentally question the validity of the rugby league tests for motor skill ability in the hands of an inexperienced observer and suggest that it would be inappropriate to use the assessments of novice or expert observers interchangeably. Indeed, Gabbett et al. (2008b) has discussed the results of previous studies that have used either a novice or an expert observer without consideration of the potential differences in interpretation. In relation to the analytical goals of perfect agreement, the degree of random variation between the scores of the expert coaches and the novice was as low as 30%, with associated CIs ranging from 19.5% to 46.8%. Furthermore, the largest perfect agreement was 65% and in no case did the comparisons between the novice and expert observers indicate the potential (via CIs) for 100% agreement. If it is the intention of future research to compare findings between different studies, than an *a priori* evaluation similar in nature to the current study should be undertaken in order to establish the reliability of the observer.

The differences found in the present study between novice and expert observers may be owing to the inconsistent use of the set criteria for skill assessment. It has been suggested that inexperienced observers over-rely on operational definitions whilst assessing technical actions during match play (O'Donoghue, 2007). In contrast, an expert observer may choose to underpin interpretations of performance with previously acquired tacit coaching knowledge, using definitions as a vague guide rather than to strictly inform assessment, even when instructed otherwise (O'Donoghue, 2007). Although such reasoning may partly explain the disparity between expert and novice coaches, it is reasonable to question the necessity of 'set criteria', particularly for the expert coaches, if it fails to inform the resultant assessment. However, in the present study the novice observer demonstrated no systematic bias and

perfect agreement ranging from 70% to 85% between repeated trials, which may support the utility of set criteria since this alone guided the interpretation of skill in the absence of sport-specific knowledge. It is therefore apparent that the set criteria may be used differently depending upon the user's prior experience of the sport. Consequently, it can only be assumed that the exact construct of skill being assessed will vary between users with more or less experience.

5.5 Conclusion

The current analysis has raised a general concern over the use of subjective ratings of rugby league skill in their current form and highlighted potential issues with the application of set skill criteria in relation to the 1 to 5 Likert scale ratings. Collectively, the inter-observer trials have shown that the application of a Likert scale cannot be used reliably to obtain a perfect agreement, most likely reflecting the subjectivity of the observers. This finding was supported by the novice's higher level of reliability demonstrated over the two repeated trials. Furthermore, it is clear that some skills, such as tackling, are inherently more difficult to assess reliably than others, perhaps owing to the open nature of the assessment method. If sport-specific skill is an underlying facet of talented performance, capable of discerning between the elite or sub-elite players, then a test based upon an objective outcome may provide a more suitable measure. However, whilst such tests offer greater control over the performed skill, a sacrifice in ecological validity is inevitable. On the basis of the current findings, the assessment of skill was not considered in the subsequent longitudinal analyses. While other assessments of 'skill', such as target drills, might have been considered, such techniques fail to conform to current conceptions of skill in team sport (Ali, 2011).

Chapter 6: A longitudinal analysis of physical growth and performance in selected and unselected youth rugby league players

6.1 Introduction

Talent in team sport is often associated with superior aspects of physical performance, such as speed, skill and endurance capacity (Vaeyens et al., 2008). Various anthropometrical measurements and maturity assessments are also used to differentiate between players of higher and lower ability and may account for performance improvements over time (Mendez-Villaneauva et al., 2011; Malina et al., 2004). Establishing differences in physiological and anthropometric characteristics of coach-selected and unselected players identifies the factors that are important for success, recognizes factors that limit success and may provide normative data for selection onto talent development programmes (Williams & Reilly, 2000).

Amongst junior rugby league players, there are clear differences in physical size and performance measures (i.e. speed and endurance) between players of different chronological ages, which become less apparent at older adolescent stages (Gabbett, 2009; Gabbett, 2005). However, such differences between playing standards appear less pronounced in comparison to other popular team sports, such as soccer and field hockey. For example, Gabbett (2009) reported either no difference ($P > 0.05$) in anthropometric characteristics, jumping, sprinting or endurance capacity between those selected to start matches (starters) and those who were not (non-starters) across under-14 to under-18 year groups. However, the results of Gabbett's study cannot be generalized since only athletes from a recreational playing standard were sampled. Furthermore the effect of maturity was not statistically controlled for which may account for performance advantages at the younger age groups (Vaeyens et al., 2006). Amongst younger (under-13 to under-15 group) rugby league players, Till et al. (2011) investigated the factors that discriminate between players of regional and national standards. Anthropometric and performance characteristics, such as chronological age, 20 m speed,

stature, body mass, sum of four skinfolds and predicted $\dot{V}O_{2\max}$ collectively explained 28.7% of the variance in playing standard. Whilst such observations provide practitioners with evidence of potential measurable facets with which to identify players of higher or lower standard, a further 71.3% of playing ability is unaccounted for. Indeed, facets that potentially determine a young player's future performance may exist within tests that are yet to be developed. Therefore, further consideration of additional, and novel, performance measurements such as peak power (Baker & Newton, 2006) or sprint momentum (Baker & Newton, 2008), which have been shown to differentiate between adult players of higher and lower playing standards, is also warranted amongst youth players.

To date, studies in youth rugby league have yet to adopt longitudinal research designs, thus limiting our understanding of the rate at which higher ability is attained over time. Previous authors, adopting cross-sectional research designs, have incorrectly claimed to have identified Annual data plots for performance (Till et al., 2011; Gabbett, 2002). For example, players are generally heavier, taller and faster sprinters in the under-15 age group compared to under-14 age group (Till et al., 2011; Gabbett, 2009), however, the time-course and magnitude of such annual developments has yet to be established. Studies evaluating longitudinal changes in growth and performance are more common in other team sports, such as soccer, where the relationship between physical growth and performance through adolescence has been demonstrated (Philippaerts, 2006). Such information would supplement current talent development processes, informing practitioners of expected performance increases across annual age groups.

The primary aim of the current study was to evaluate changes in annually collected anthropometric and performance data of groups of youth rugby league players that were successful in progressing through successive age groups, leading to adult transitions. This process enabled an evaluation of the typical development rates in players progressing through each year group. In a separate analysis of the same anthropometric and performance data, players that were either selected or unselected by the coaching staff at each age group were compared in order to establish the factors that differentiated between these groups. The relationship between variables of physical performance and anthropometry was also evaluated to identify some of the potential mechanisms responsible for superior performance across different age groups.

6.2 Method

6.2.1 Participants

Twenty eight elite youth rugby league Scholarship/Academy players provided informed consent (Appendix 2) to take part in a three-season longitudinal study. Ethical approval was granted by the Faculty of Applied Sciences Ethics Committee. All players were part of a structured development programme, which was monitored by sport scientists and qualified coaching staff employed by one English professional rugby league club. The players were monitored over a three-season period (under-15 group to the under-17 group; February 2010 to July 2012), with the players' birth dates falling within the years of 1994/5. The players were not sub-categorized into positional groups owing to the smaller sample sizes.

6.2.2 Design

Each player took part in an annual battery of tests, which was undertaken within the same month of each year, before the start of the competitive playing season. The tests included measures of linear running speed and acceleration, neuromuscular power and aerobic capacity. Questionnaires relating to the degree of formal training experience were also completed prior to testing. Anthropometry measures were subsequently performed one month after the season had commenced due to the availability of players for testing. At the end of each annual period (season), a group of coaches ($n = 6$) involved with the club either selected or unselected players based upon their typical subjective selection criteria (of which there were no formal guidelines). The selected players went on to play for the club in the following season, whereas the unselected players were released to play amateur rugby. Throughout the study period, the same coaches were responsible for the selection of players through to the next annual stage, which yielded the sample sizes described in Table 6.1.

Table 6.1. Sample sizes (n) of the selected (S) and unselected (Un) players at the end of each year group

Under-15 group		Under-16 group		Under-17 group		Three-season cohort
S	Un	S	Un	S	Un	
$n = 16$	$n = 5$	$n = 14$	$n = 8$	$n = 8$	$n = 6$	$n = 13$

Following the three season period, a sub-section of the original sample ($n = 13$), comprising players that had successfully competed within each age group was retained in order to evaluate developmental patterns over the study period.

6.2.3 Physical performance procedures

All tests of sprinting, acceleration, jumping and aerobic capacity took place outside on the same rugby field in the North West of England. Mean temperature was $9.7 \pm 2.4^{\circ}\text{C}$ throughout the three year period. The chosen field was flat, well maintained by ground staff and free from obstruction or adjacent buildings. All participants wore the same standard squad clothing, including studded boots, at each trial and performed a standardised familiarization and warm-up prior to each performance test that included moderate intensity running and dynamic stretching routines.

6.2.4 Linear running speed

One week prior to testing, participants completed a habituation protocol, comprising three maximal sprint efforts at each sprint interval (10 m, 20 m & 30 m), separated by three minutes passive recovery. Suitable habituation to the testing protocol was established when no systematic learning effect was evident (after three sprints) and when participants voluntarily indicated that the procedure for testing was understood. In order to prevent participants from decelerating prior to reaching the final timing gate (30 m), thus failing to reach or maintain true peak speed through 30 m, an additional coloured cone was placed at 35 m to which participants were instructed to consider as the finish point. Using the GPS equipment (described below) for verification, no indication of pre-emptive deceleration was demonstrated, with all participants consistently attaining peak speed after the 30 m distance.

Testing took place on a still, calm day, across the centre of an open field, free from obstruction or adjacent buildings, thus preventing multipath effects (i.e. deflected GPS

signal). All GPS units were simultaneously activated on the open ground and left for 15 minutes to ensure that an appropriate signal had been attained and to maintain an equal potential for drift error associated with the in-built accelerometer in each GPS unit (GPSports, 2010). The GPS units (size = 90 x 45 x 5 mm; mass = 86 g) sample at a rate of 5 Hz and are coupled with a tri-axial accelerometer sampling at 100 Hz. The typical number of available satellite signals was between 9 and 11 throughout the testing period and the horizontal DOP (HDOP) was recorded at 1.24 ± 0.3 . GPS vests (GPSports, Canberra, Australia) were tightly fitted to each participant in accordance with the manufacturer's guidelines. Vests were worn on top of a standard squad training shirt, thus placing the receiver approximately between the scapulae of the participant. Twenty minutes before exercise, players were taken for a structured warm-up led by the squad coach, consisting of moderate intensity movement, light dynamic stretching procedures and two maximal sprints.

The protocol consisted of two maximal sprint efforts, starting from a standing position, over a flat, grass surface, separated by a period of three minutes of recovery. The brief testing period and close proximity of repeated trials was also intended to reduce the effect that transient changes in the dilution of precision (DOP) measurement may inflict on calculations of distance and speed. Indeed, the mean horizontal dilution of position (HDOP) was recorded at 1.2 ± 0.2 throughout the testing period, ensuring near optimal conditions for testing (Jennings et al., 2010). The correct sprinting course was marked with a pre-measured (tape measure) straight painted line, orthogonal to a light prevailing wind, upon which timing gates were positioned at 10 m intervals (0-30 m), as shown in Figure 6.1. At each interval, timing gate height was set at 60 cm (see Cronin & Templeton, 2008). On both occasions, participants were instructed to start sprinting from 30 cm behind the first timing gate, off their preferred foot, in order to prevent a pre-mature breaking of the infra-red beam. Participants were

further instructed to begin sprinting from a static position in order to prevent pre-emptive backwards movement prior to accelerating (Frost et al., 2008). Split times were recorded at 10 m, 20 m and 30 m from a wireless receiver (Brower timing systems, Utah, USA) accurate to 0.01 s. All data were later downloaded to a personal computer using SPI EZY (V2.1, GPSports, Canberra, Australia) software and, subsequently, analyzed *post-hoc* using Team AMS software (V2.1, GPSports, Canberra, Australia). Using Team AMS software, the initiation of a sprint was determined by a continuous increase in speed from below 0.01 km·h⁻¹ (Petersen et al., 2009).

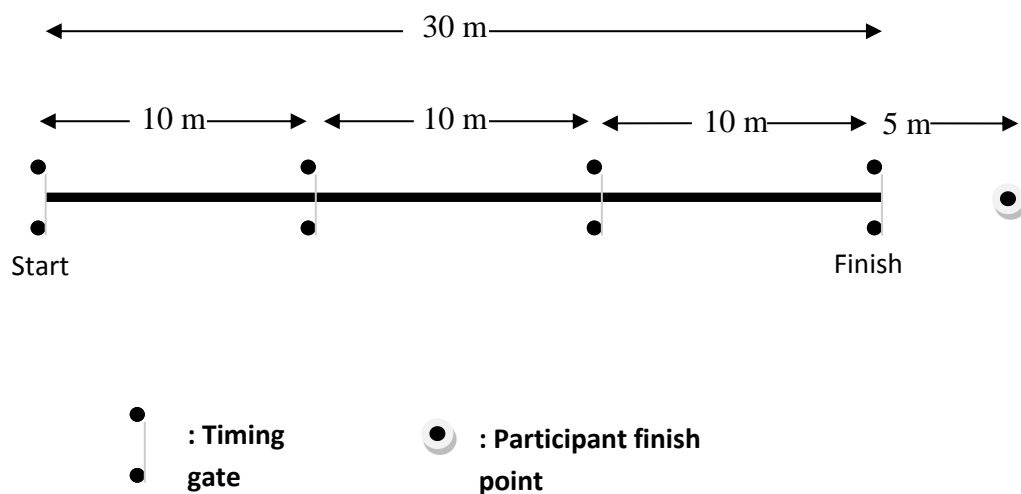


Figure 6.1. Schematic of sprinting assessment procedure (not to scale).

6.2.5. Linear acceleration

Acceleration ($\text{m}\cdot\text{s}^{-2}$) from standing to 10 and 30 m was calculated manually using data recorded by the GPS during the over-ground sprinting protocol. Using the raw GPS file the formula used for linear acceleration was;

$$a = \frac{\Delta v}{\Delta t}$$

Where: a = acceleration ($\text{m}\cdot\text{s}^{-2}$); Δv = change in velocity ($\text{m}\cdot\text{s}^{-1}$); Δt = change in time (s)

6.2.6. Sprinting force and power assessment

Force (N) and power (W) were calculated from the linear sprinting protocol over 10 m and 30 m using the following equations;

$$f = m \times a$$

$$p = \frac{(f \times d)}{t}$$

where: f = force (N), m = body mass (kg), a = acceleration ($\text{m}\cdot\text{s}^{-2}$); p = power (W); t = time (s)

6.2.7 Vertical jumping assessments

Vertical jumping performance was assessed using both squat and countermovement techniques. The players were instructed to wear training shoes for the jump analysis. Both

jump height (cm) and flight time (s) (calculated as the difference between landing and take-off time) was recorded using a timing mat system (Just Jump System, Probotics Inc., Huntsville, AL). The participants performed three jumps with the highest jump used for analysis. All participants underwent familiarization sessions one week prior to analysis and frequently performed vertical jumping techniques as part of a regular monitoring process throughout the season. The reliability of the countermovement and squat jump heights was examined within the first year of testing and demonstrated a CV of 2.4% and 2.9%, respectively, no systematic bias ($P > 0.05$) and 95% Limits of Agreement (95% LoA) of -0.15 ± 1.15 cm and -0.08 ± 1.32 cm, respectively. It was important to establish the reliability of jump height since this variable is used to calculate power in the following prediction model on p. 154 (Harman et al., 1991).

In the squat jump condition, participants were required to start from a semi-squatted position and to jump for maximal height (Bobbert & Casius, 2005). The importance of avoiding a preparatory countermovement was discussed and demonstrated by the researcher in order to minimise the possible effect of pre-movement silent periods or small amplitude counter movements (Dugan et al., 2004). To standardise the starting position, the participant was requested to maintain a stance at shoulder width, facing the same direction on the jump mat. A self-selected foot position was assumed by the participant. Upon a cue from the researcher, the participant was required to flex down until a knee angle of 90° was attained and hold this for two seconds (Gerodimos et al., 2008). Once stabilised in this position, the participant was free to perform the jump, ensuring that his legs were fully extended until landing. The participant's arms remained rested on his hips throughout the jump.

For the countermovement jump condition, participants were verbally and visually instructed on how to perform a countermovement jump. Emphasis was placed on achieving a rapid eccentric (downward) motion, reaching 90° flexion, followed by an explosive concentric phase (upward motion) (Bobbert & Casius, 2005). Feet and hand position did not differ from that of the squat jump condition. Power (W) was estimated from countermovement jumps based upon the equation of Harman et al. (1991) (below). The equation of Harman and colleagues was selected since reports have demonstrated no systematic difference to power recorded on a force platform (Canavan & Vescovi, 2004).

Countermovement jump power (W) =

$$61.9 \times \text{jump height (cm)} + 36.0 \times \text{body mass (kg)} - 1822$$

(Harman et al., 1991)

6.2.8 Aerobic capacity assessment

Maximal aerobic endurance was estimated using the multistage fitness test (Leger & Lambert, 1982). Players were required to run back and forth between two cones placed 20 m apart, keeping in time with a series of audio signals played through a CD player. The frequency of the signals and subsequent running speed was progressed by 0.5 km·h⁻¹ increments, starting from 8 km·h⁻¹, until participants reached volitional exhaustion. Players were fitted with GPS equipment (see above) and heart rate (HR) telemetry (Polar-electro, Oy, Finland) in order to record the peak HR upon completion of the test. In the event of a player missing the audio cue, a verbal warning was issued. If three cues were missed the player was removed from the protocol. Maximal aerobic capacity ($\dot{V}O_{2\text{max}}$) was later determined using

the linear regression equation proposed by Ramsbottom et al. (1988). In rugby league players ranging between the ages of 15 to 18 years, the intra-class correlation coefficient for test re-test reliability and typical error of measurement for the multistage fitness test have previously been reported as 0.90 and 3.1%, respectively (Gabbett et al., 2008a).

6.2.9 Anthropometry procedures

6.2.10 Skinfold measurement

Participants were required to stand in an anatomical position (Figure 6.2) whilst being palpated by the researcher for body land marks. Once the appropriate land mark had been located, a total of six skinfold sites, included within the International Society for the Advancement of Kinanthropometry (ISAK) standard criteria (Hume & Marfell-Jones, 2008), were marked out upon the right hand side of the participant's body using a fine point felt tip pen and a tape measure (Ross & Marfell-Jones, 1991). The sites included; triceps, biceps, sub-scapular, abdomen, front thigh and pectoral which were located as presented in Figure 6.2. The directions for palpation and marking of each site were based on Norton and Olds (2000). Skin-folds were measured using pre-calibrated Harpenden (British Indicators, UK) callipers, used according to the technique described previously (Norton & Olds, 2000; Pollock & Jackson, 1984). This method encourages the use of the thumb and index finger to grasp the skin in the marked location. The jaws of the calliper were opened and placed perpendicular to the skinfold and slowly released onto the participant's skin at an even and constant pressure. The reading was taken by the researcher from a direct line of vision to reduce the effects of parallax error. The value was attained as soon as possible in order to reduce the effect of adipose tissue deformation (Pollock & Jackson, 1984).

Each site was measured three times from which the median value was recorded (Norton & Olds, 2000). Body fat percentage was predicted using the equation of Jackson and Pollock (1978). Intra-tester reliability from two trials performed on different occasions ranged from 1.2% to 3.5% (CV) and 0.25 to 2.2 mm (95% LoA), with no systematic bias demonstrated (Figure 6.2).

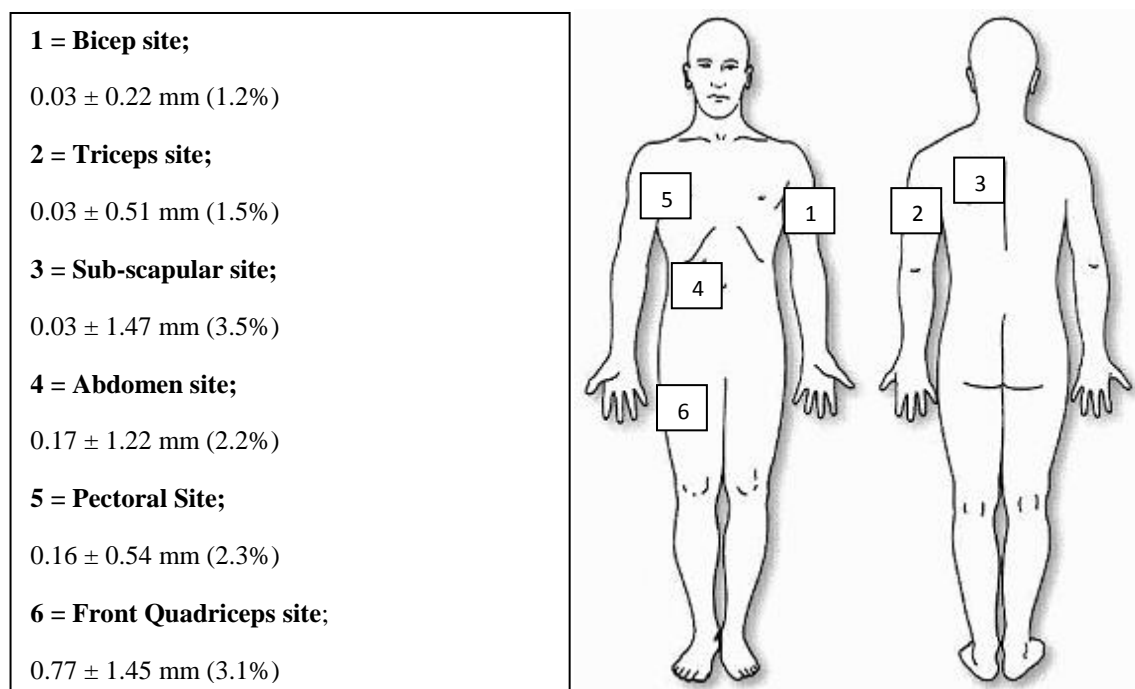


Figure 6.2. Anterior (left) and posterior (right) view of an anatomical model with skinfold locations marked. Reliability indices are reported as 95% LoA and CV%.

6.2.11 Stature, mass and limb length measurement

Stature and seated stature were measured using a portable stadiometer (Seca, Leicester height measure, Hamburg, Germany). For seated stature participants were seated on a flat, hard surfaced bench of a known vertical height, which was used throughout the three-year period. The stretch stature technique was used in each case with measurements being recorded to the nearest 0.1 cm. Leg length was derived from the subtraction of seated stature from overall stature (Malina et al., 2004). Body mass was measured using Seca beam scales (Seca, Hamburg, Germany) to the nearest 0.1 kg, with players wearing only the standard squad shorts and socks (the kit being worn was weighed and subsequently deducted from the final result). The approximate length of both the humerus and femur were measured in accordance with the guidelines of Lovell et al. (2005). Humerus length was measured through palpation of the acromion, following from the lateral lip to the greater tuberosity, which is inferior to the acromion's internal edge. From this point, the examiner measured the length of the humerus to the lateral epicondyle to complete the measurement, which was recorded with a tape measure on the right hand side of the body to the nearest 0.1 cm. Femur length was obtained by initially seating the participant at the appropriate height in order to reach 90° flexion of the knee joint (which was verified using a goniometer on the right hand side). Femur length was measured as the distance from the anterior superior iliac spine to a square plate positioned on the surface of the patella rather than following the surface of the leg to avoid bending of the measurement tape. Each site was measured three times from which a median value was obtained. Intra-tester reliability (95% LoA and CV%) from two trials performed on two occasions separated by one hour was 0.15 ± 1.77 cm (1.8%) and -0.14 ± 0.83 cm (0.5%) for the humerus and femur measurements, respectively, with no systematic bias present for any measurement.

6.2.12 Muscle circumference measurement and predicted cross-sectional area (CSA)

Muscle circumference measurements were taken from each player in accordance with the guidelines of Mirwald et al. (2002) and Malina et al. (2004). These included: quadriceps, upper arm, calf and chest circumferences, recorded on the right-hand side of each participant's body (apart from chest circumference). The participants were firstly marked using a fine-point felt tip pen and subsequently measured using a measuring tape to the nearest 0.1 cm on the appropriate anatomical landmarks. Marking and measurement of the quadriceps circumference involved the participant standing with his right hip, knee and ankle flexed in front of him, placing their foot in a 90° position on a bench (verified using a goniometer). The measurement of the mid-line of the quadriceps was attained after the previous marking of the mid-point between the iliac crest and the greater trochanter. The measurement of upper arm circumference was obtained with the participant in the anatomical position, with the mid-line of the upper arm identified using the mid-point of the humerus measurement previously described. The reliability was established (using 95% LoA and the CV%) as: quadriceps = -0.61 ± 0.54 cm (2.3%); upper arm = 0.26 ± 1.06 cm (1.2%); calf = 0.17 ± 1.12 cm (1.1%); chest = 0.07 ± 4.15 cm (1.4%).

The muscle cross-sectional area (CSA) of the right quadriceps region was predicted using the multiple regression equation of Housh et al. (1995), whereby;

$$\text{CSA} = (4.68 \times \text{quadriceps circumference}) - (0.64 \times \text{quadriceps skinfold}) - 22.69$$

The equation of Housh and colleagues has an error of between 5 cm² and 14.3 cm² for quadriceps muscle CSA and has been suggested as a viable indirect alternative to criterion measurements in young athletic populations (Housh et al., 1995).

6.2.13 Chronological age and age at Peak Height Velocity (PHV)

The chronological age of participants was calculated as the difference between their date of birth and the date on which the tests were performed. This value was decimalised using a formula available on Microsoft Excel (2010). The maturity offset value (i.e. the difference between age at PHV and chronological age) was determined using the multiple regression model of Mirwald et al. (2002) where;

Maturity Offset = -9.236 + 0.0002708·LL and SH interaction - 0.001663·Age and LL interaction + 0.007216·Age and SH interaction + 0.02292·BM by S ratio,

Where; LL = leg length, SH = seated height; BM = body mass; S = stature

The adjusted coefficient of determination (R^2) of the above equation was reported as 0.89 with a standard error (SE) of 0.59 years (Mirwald et al., 2002). The age at PHV was obtained by adding or subtracting the offset value to chronological age. A positive value meant that the participant was post-PHV whilst a minus value meant that the participant was pre-PHV. Whilst other predictions of maturity status were available for use with adolescent players of the current cohort (see Beunen et al. 1997), their predictive ability is based upon recreationally active and sedentary populations and, therefore, is less appropriate with athletic populations. This is pertinent to rugby league players who often exhibit triceps skinfolds that

are relatively larger than the accompanying components of the model advocated by Beunen and colleagues.

6.2.14 Statistical analyses

Descriptive statistics (mean \pm SD) were calculated for each dependent variable and are presented in Figures 6.3 – 6.18. After the appropriate diagnostic checks for normality and sphericity, one-way repeated-measures analyses of variance (one-way RM-ANOVA) were used to identify overall differences in measurements of anthropometry and performance amongst the players competing within years one, two and/or three (coach-selected), represented by the under-15, -16 and -17 age groups. Specific differences were identified using paired *t*-tests and a Benjamini Hochberg false discovery rate adjustment to control the type I error rate (Benjamini & Hochberg, 1995).

Differences in measurements of anthropometry and performance between all selected or unselected players at the conclusion of each year were identified using independent *t*-tests and a Benjamini Hotchberg false discovery rate adjustment to control for type I error. A secondary process, using a series of ANOVAs with age at PHV as the covariate (analysis of covariance; ANCOVA) and selection status as the between-group variable, was applied in order to control for the effects of maturation on performance and anthropometric variables. After checks for the equality of variance using Box's *M* ($P > 0.05$), a stepwise discriminant function analysis was conducted in order to predict the combination of factors that underpin the selecting or unselecting of players at each year group. All of the outcome measures

previously identified were considered as predictor variables. Significance was set at $P < 0.05$ for all statistical processes.

Pearson's correlation coefficient (r) was used to assess the bivariate relationships between each anthropometric variable (aside from individual skinfold measurements) and the tests of physical performance for each year of competition. The r value was interpreted according to arbitrary values suggested by Cohen (1992) where 0.1 = small, 0.3 = medium and 0.5 > = large. Data analysis was performed with the SPSS version 19.

6.3 Results

6.3.1 Performance measures: Three season coach-selected group

Results from the RM-ANOVAs showed time effects for 10 m sprint time ($F_{(2,24)} = 11.642$, $P < 0.001$), 20 m sprint time ($F_{(2,24)} = 11.9$, $P < 0.001$) and 30 m sprint time ($F_{(2,24)} = 4.567$, $P = 0.021$). As presented in Figure 6.3, *post-hoc* tests revealed differences between the under-15 group and under-16 group for 10 m sprint time (2.17 ± 0.08 s c.f. 2.06 ± 0.13 s, respectively; $P = 0.049$), 20 m sprint time (3.49 ± 0.12 c.f. 3.35 ± 0.18 s, respectively; $P = 0.008$) and 30 m sprint time (4.71 ± 1.82 c.f. 4.56 ± 0.24 s, respectively; $P = 0.020$). Differences were also seen between the under-15 group and under-17 group for 10 m (2.17 ± 0.08 c.f. 2.01 ± 0.45 s, respectively; $P < 0.001$), 20 m (3.49 ± 0.12 c.f. 3.29 ± 0.75 s, respectively; $P < 0.001$) and 30 m sprint times (4.57 ± 0.12 s; $P = 0.014$). However, no differences ($P > 0.05$) were found in sprint time between the under-17 group and the under-16 group for any sprint distance.

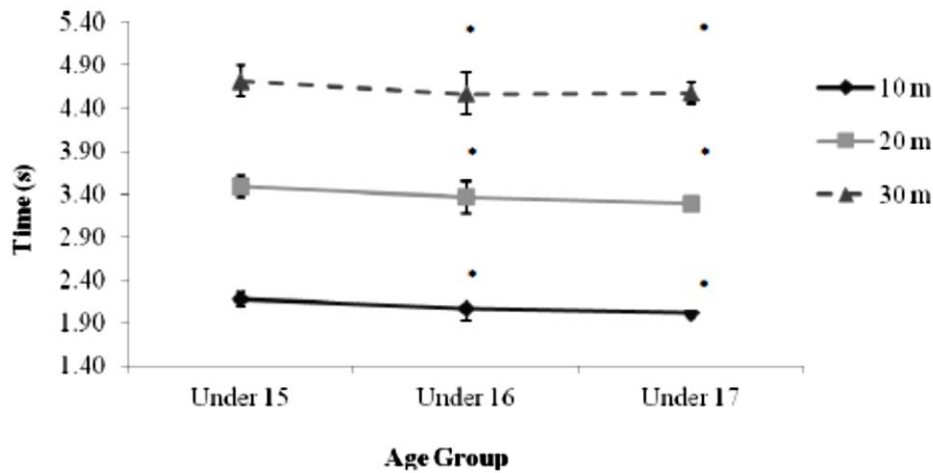


Figure 6.3. Annual data plots for 10 m, 20 m and 30 m sprinting ability for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group.

As shown in Figure 6.4, there were no time effect on 30 m peak sprint speed ($F_{(2,24)} = 1.428$, $P = 0.260$) or 10 m peak sprint speed ($F_{(2,24)} = 0.140$, $P = 0.870$). However, the effect of time was significant for acceleration over 10 m ($F_{(2,24)} = 6.3$, $P = 0.008$), with specific differences occurring between the under-15 group and under-16 group (3.16 ± 0.29 c.f. 3.35 ± 0.29 $\text{m}\cdot\text{s}^2$, respectively; $P = 0.047$) and under-15 group to under-17 group (3.16 ± 0.29 c.f. 3.41 ± 0.23 $\text{m}\cdot\text{s}^2$, respectively; $P = 0.006$). No time effect was apparent for 30 m acceleration ($F_{(2,24)} = 1.234$, $P = 0.309$) (Figure 6.5).

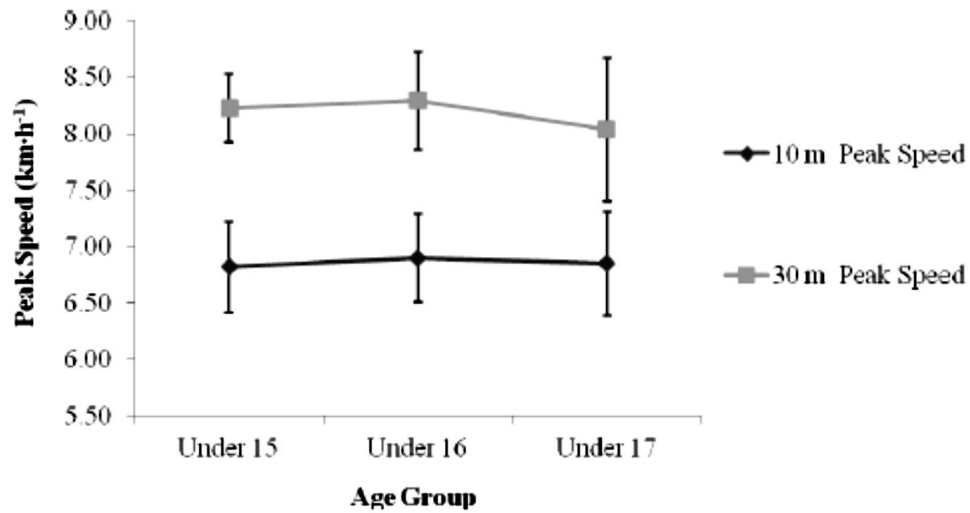


Figure 6.4. Annual data plots for 10 m and 30 m peak sprinting speed for players selected over three successive seasons ($n = 13$).

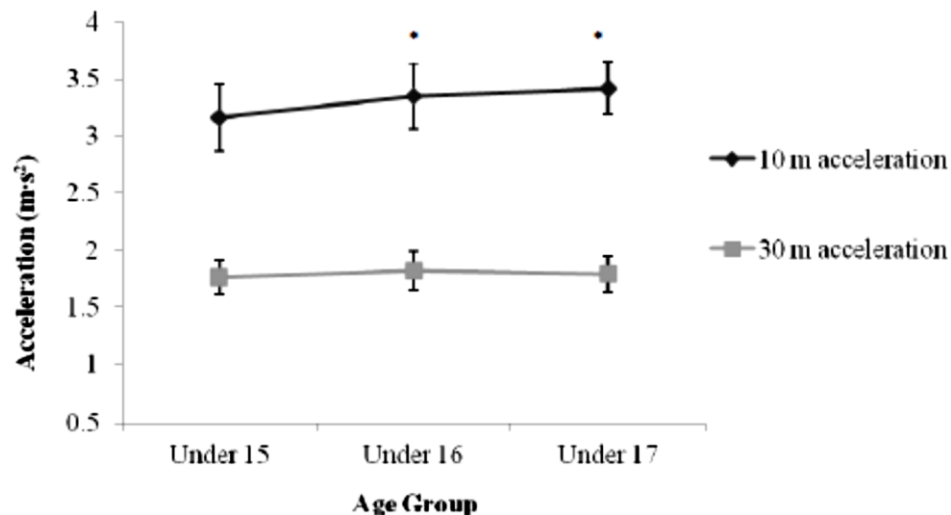


Figure 6.5. Annual data plots for 10 m and 30 m acceleration for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group.

For force data (mass \times acceleration), there were time effects shown over 10 m intervals ($F_{(2,24)} = 16.673$, $P < 0.001$) with pairwise differences (Figure 6.6) revealed between the under-

15 group and under-16 group (243.0 ± 31.9 c.f. 276.1 ± 36.1 N, respectively; $P = 0.003$) and under-15 group to under-17 group (243 ± 31.9 c.f. 286.1 ± 31 N, respectively; $P < 0.001$). Further time effects were apparent for force exerted over 30 m ($F_{(2,24)} = 8.116$, $P = 0.002$) which was attributable to differences between the under-15 group and under-16 group (135.8 ± 17.5 c.f. 150.5 ± 21.1 N, respectively; $P = 0.006$) and under-15 group to under-17 group (135.8 ± 17.5 c.f. 149.4 ± 20.1 N, respectively; $P = 0.008$).

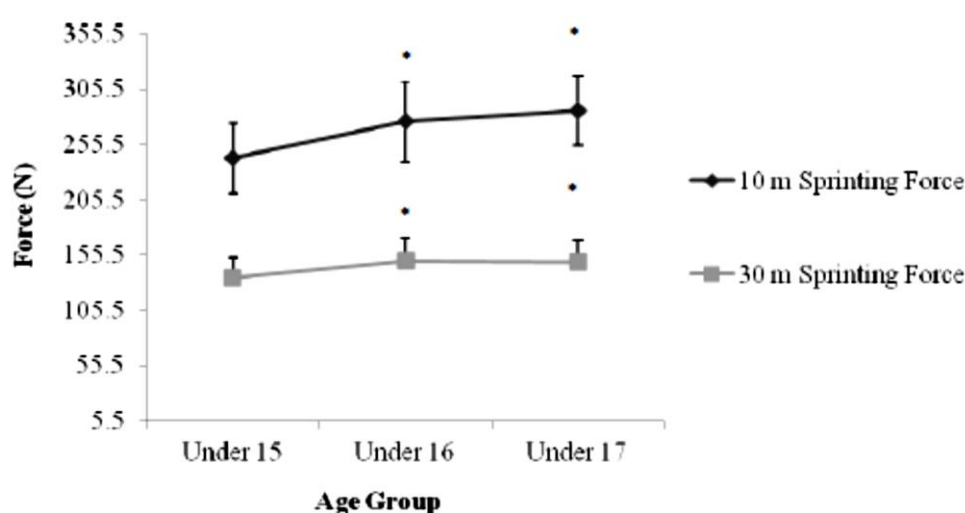


Figure 6.6. Annual data plots for 10 m and 30 m force for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group.

There were time effects for power (Figure 6.7) exerted over both 10 m ($F_{(2,24)} = 20.548$, $P < 0.001$) and 30 m distances ($F_{(2,24)} = 8.782$, $P < 0.001$). For 10 m power, *post-hoc* tests revealed differences between the under-15 group and under-16 group (1123 ± 181.1 c.f. 1345.6 ± 201.9 W; $P < 0.001$) and the under-15 group and under-17 group (1123 ± 181.1 c.f. 1417.6 ± 161.9 W, respectively; $P < 0.001$). The same was true for 30 m power with differences between the under-15 group and -16 group (868.5 ± 139.5 c.f. 994.4 ± 167.1 W, respectively; $P = 0.006$) and the under-15 group and under-17 group (868.5 ± 139.5 c.f. 984.4 ± 186.2 W, respectively; $P = 0.005$) (Figure 6.7).

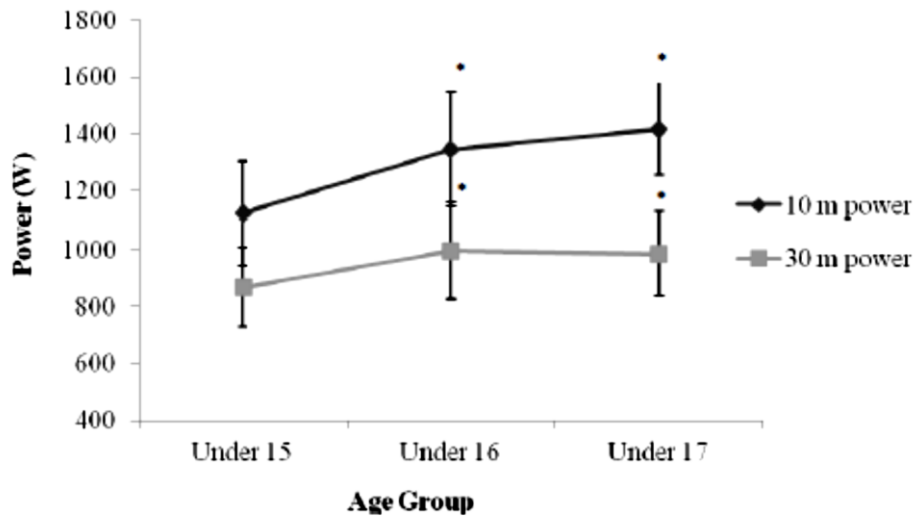


Figure 6.7. Annual data plots for 10 m and 30 m power output for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group.

There were no time effects for countermovement jump height ($F_{(2,24)} = 1.409$, $P = 0.906$) or squat jump height ($F_{(2,24)} = 2.331$, $P = 0.119$), however, a time effect was noted for predicted vertical power ($F_{(2,24)} = 14.845$, $P < 0.001$) (Figure 6.8). As with all other performance measurements, *post-hoc* tests showed differences between the under-15 group and under-16 group (3611.2 ± 327.9 c.f. 4081.4 ± 453.9 W, respectively; $P = 0.003$) and the under-15 group and under-17 group in favour of the older age groups (3611.2 ± 327.9 c.f. 4141.3 ± 397.1 W, respectively; $P < 0.001$).

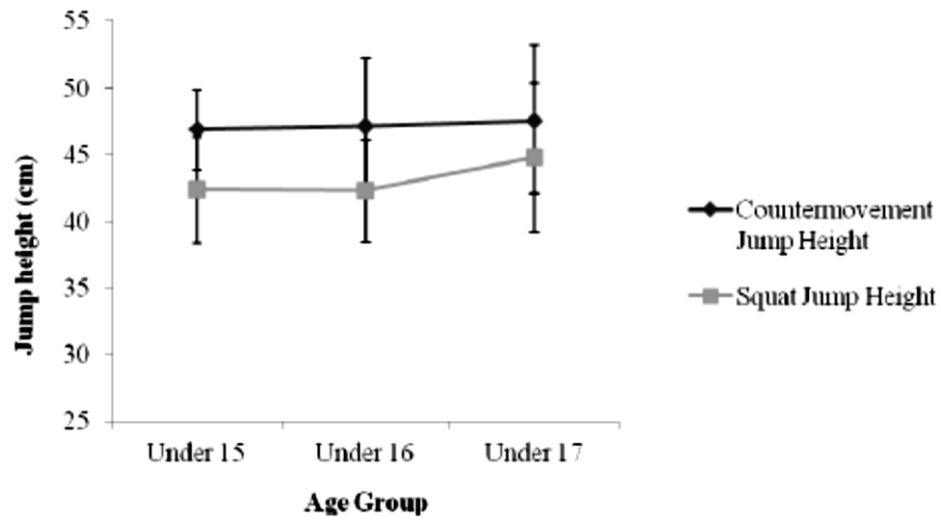


Figure 6.8. Annual data plots for countermovement and squat jump performance for players selected over three successive seasons ($n = 13$).

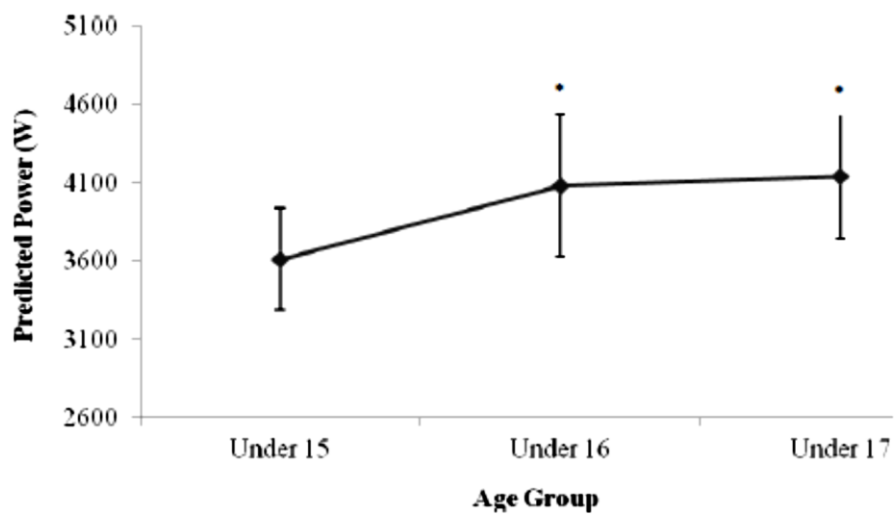


Figure 6.9. Annual data plots for predicted CMJ power output for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group.

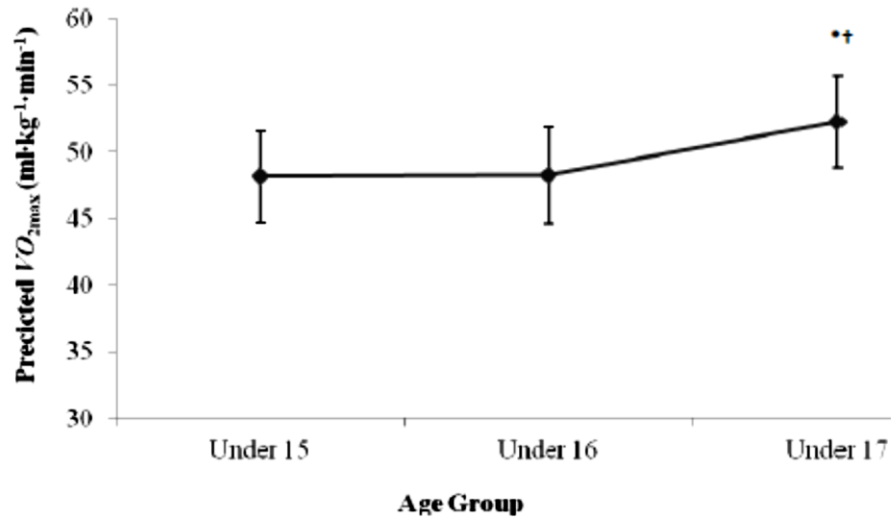


Figure 6.10. Annual data plots for predicted $\dot{V}O_{2\max}$ (ml·kg⁻¹·min⁻¹) for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group stage; † = significantly different ($P < 0.05$) to the under-16 group.

A time effect was found for predicted $\dot{V}O_{2\max}$ (ml·kg⁻¹·min⁻¹) ($F_{(2,24)} = 5.789$, $P < 0.001$), which was attributable to lower values in the under-16 group compared to the under-17 group (48.28 ± 8.62 ml·kg⁻¹·min⁻¹ c.f. 52.25 ± 3.46 ml·kg⁻¹·min⁻¹, respectively; $P < 0.001$) and in the under-15 group compared to the under-17 group (48.14 ± 3.14 ml·kg⁻¹·min⁻¹ c.f. 52.25 ± 3.46 ml·kg⁻¹·min⁻¹, respectively; $P < 0.014$) (Figure 6.10). The mean development rates for each of the physical performance tests are presented in table 6.2.

Table 6.2. Mean rates of development and percentage changes over successive annual periods in measurements of closed performance

	Year 1-2 mean rate of change (n·year ⁻¹)	Mean %Δ	Year 2-3 mean rate of change (n·year ⁻¹)	Mean %Δ
Predicted $\dot{V}O_{2\max}$ (ml·kg⁻¹·min⁻¹)	0.13 ± 4.49	0.29	3.69 ± 2.74	8.22
10 m mean time (s)	-0.10 ± 0.11	-5.02	-0.05 ± 0.15	-2.46
20 m mean time (s)	-0.12 ± 0.15	-3.79	-0.06 ± 0.17	-2.07
30 m mean time (s)	-0.14 ± 0.20	-3.17	0.01 ± 0.21	0.19
10 m peak speed (m·s⁻¹)	0.07 ± 0.53	1.15	-0.05 ± 0.49	-0.73
30 m peak speed (m·s⁻¹)	0.06 ± 0.40	0.77	-0.23 ± 0.53	-3.00
10 m acceleration (m·s⁻²)	0.18 ± 0.31	6.26	0.06 ± 0.24	1.94
30 m acceleration (m·s⁻²)	0.06 ± 0.13	3.39	-0.04 ± 0.12	-2.11
Force 10 m (N)	31.25 ± 32.90	13.85	8.69 ± 26.71	3.39
Force 30 m (N)	13.65 ± 15.94	10.82	-1.01 ± 11.77	-0.72
Mean power 10 m (W)	206.69 ± 193.87	19.82	-9.20 ± 97.76	5.34
Mean power 30 m (W)	116.89 ± 134.01	14.49	66.78 ± 179.38	-0.10
CMJ jump height (cm)	0.27 ± 4.74	0.62	0.33 ± 6.01	0.77
Squat jump height (cm)	-0.09 ± 4.91	-0.23	2.36 ± 5.40	6.02
Predicted vertical power (W)	436.62 ± 449.57	13.02	55.56 ± 408.02	1.47

6.3.2 Anthropometry: Three-season selected youth rugby league group

Figure 6.11 highlights the significant time effect on stature ($F_{(2,24)} = 12.321$, $P < 0.001$), with the group growing taller between the under-15 and under-16 age groups (179.2 ± 4.6 cm c.f. 179.9 ± 4.5 cm, respectively; $P = 0.004$). A time effect was also found for seated stature ($F_{(2,24)} = 14.624$, $P < 0.001$), with follow-up paired t -tests showing specific differences between the under-15 group and under-16 groups (93.4 ± 2.3 cm c.f. 94.5 ± 2.2 cm, respectively; $P = 0.003$). There were no significant time effects found for Leg length ($F_{(2,24)} = 1.395$, $P = 0.267$).

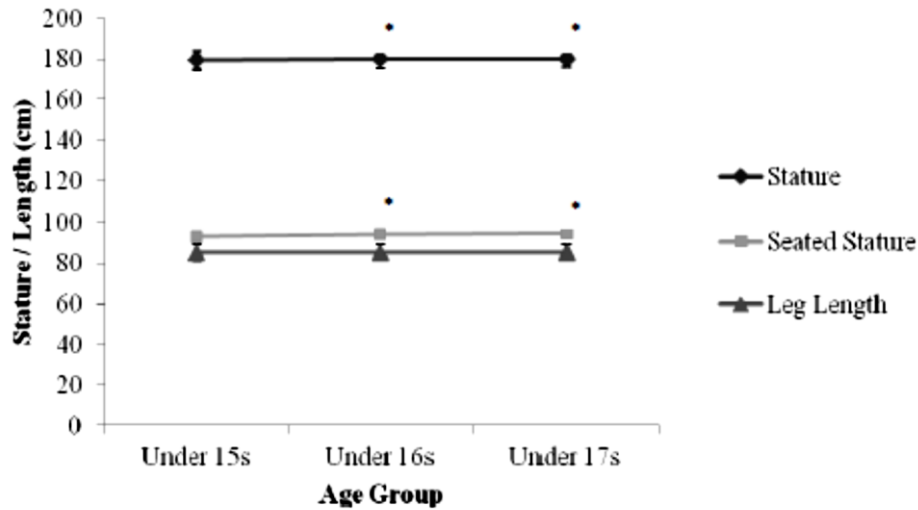


Figure 6.11. Annual data plots for stature, seated stature and leg length (cm) for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group stage.

Femur length increased over time ($F_{(2,24)} = 5.261$, $P = 0.013$) with specific differences between the under-15 group and under-16 group (44.2 ± 1.9 cm c.f. 45.2 ± 2.2 cm, respectively; $P = 0.003$). No changes in humerus length were observed over time ($F_{(2,24)} = 0.91$, $P = 0.913$) (Figure 6.12).

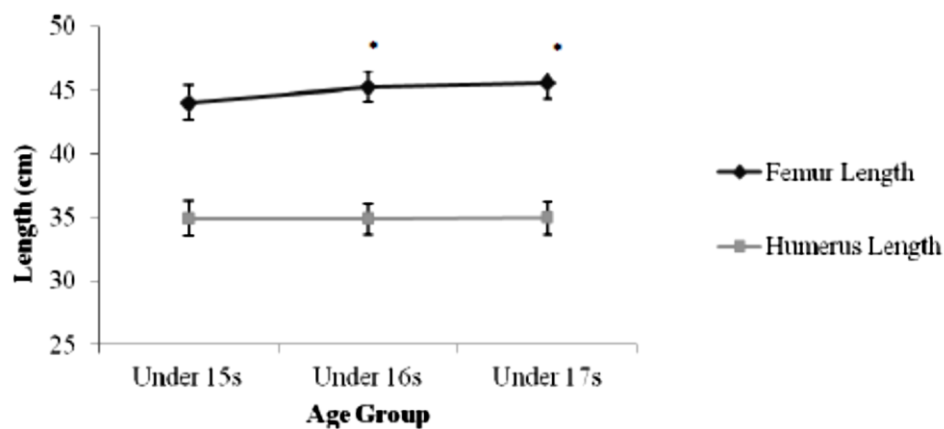


Figure 6.12. Annual data plots for humerus and femur length (cm) for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group stage.

Quadriceps circumference changed over time ($F_{(2,24)} = 3.866$, $P = 0.035$) between the under-15 group and under-17 group (57.96 ± 4.39 cm c.f. 59.9 ± 4.89 cm, respectively; $P = 0.040$) and the under-16 group and under-17 group (58.12 ± 3.9 cm c.f. 59.9 ± 4.89 cm, respectively; $P = 0.043$). The ANOVA also revealed significant time effects for chest circumference ($F_{(2,24)} = 5.402$, $P = 0.012$), which were a result of annual changes between the under-16 group and under-17 group (102.06 ± 6.21 cm c.f. 105.26 ± 5.41 cm, respectively; $P = 0.006$) and between the under-15 group and under-17 group (102.2 ± 5.84 cm c.f. 105.26 ± 5.41 cm, respectively; $P = 0.013$). Whilst upper arm circumference ($F_{(2,24)} = 1.138$, $P = 0.337$) or calf circumference ($F_{(2,24)} = 1.448$, $P = 0.225$) did not change over time (Figure 6.13), predicted quadriceps muscle cross-sectional area (CSA) did show time-related changes ($F_{(2,24)} = 11.140$, $P < 0.001$) (Figure 6.14). Paired t -tests showed that there were differences between the under-16 group and under-17 group (133.17 ± 36.02 cm² c.f. 154.84 ± 28.31 cm², respectively; $P = 0.006$) and the under-15 group and under-17 group (120.93 ± 37.83 cm² c.f. 154.84 ± 28.31 cm², respectively; $P = 0.004$).

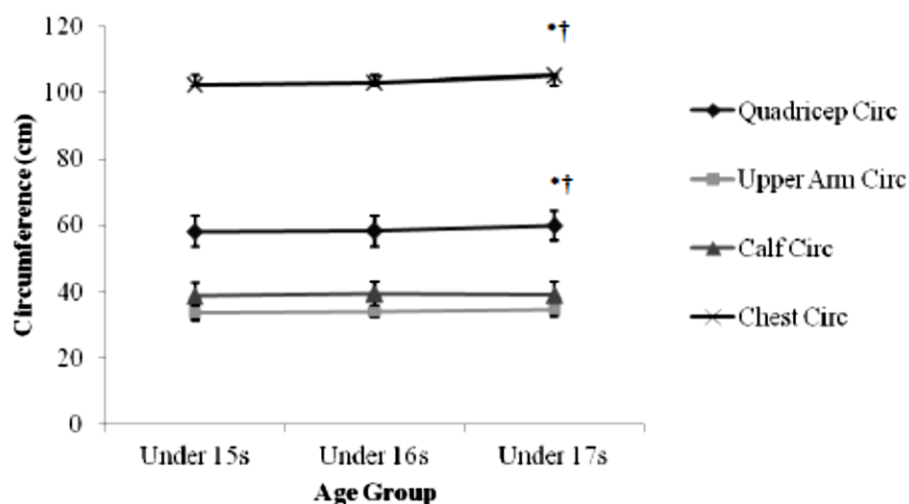


Figure 6.13. Annual data plots for quadriceps, upper arm, calf and chest circumference (cm) for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group stage; † = significantly different ($P < 0.05$) to the under-16 group stage. Circ = circumference.

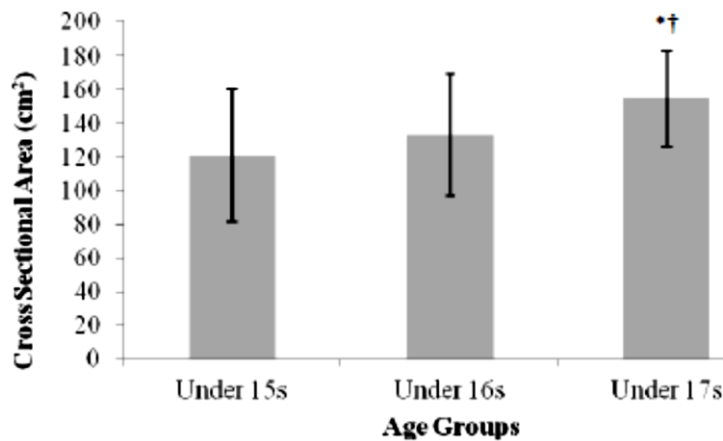


Figure 6.14. Annual data plots for quadriceps cross-sectional area (cm²) for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group stage; † = significantly different ($P < 0.05$) to the under-16 group stage.

Body mass changed over time ($F_{(2,24)} = 2.339$, $P = 0.011$) between the under-15 group and under-17 group (81.86 ± 9.11 kg c.f. 86.27 ± 9.39 kg, respectively; $P = 0.017$) and the under-15 group and -16 group (81.86 ± 9.11 kg c.f. 86.11 ± 6.22 kg, respectively; $P = 0.020$). Accordingly, lean body mass also changed over time ($F_{(2,24)} = 6.522$, $P = 0.005$) with differences found between the under-16 group and under-17 group (71.84 ± 5.77 % c.f. 74.14 ± 5.68 %, respectively; $P = 0.007$) and the under-15 group and the under-17 group (70.88 ± 5.87 % c.f. 74.14 ± 5.68 %, respectively; $P = 0.008$) (Figure 6.15).

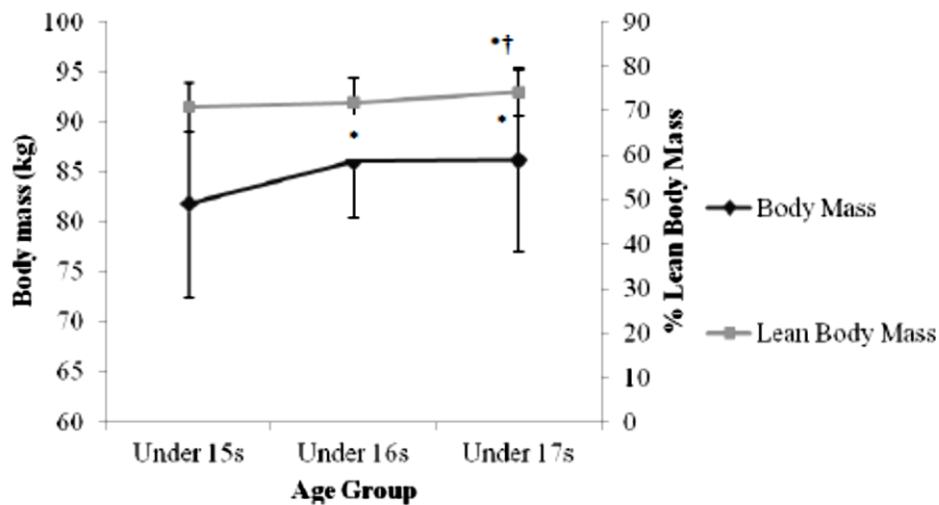


Figure 6.15. Annual data plots for body mass (kg) and lean body mass (%) for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group stage; † = significantly different ($P < 0.05$) to the under-16 group stage.

As presented in Figure 6.16, the ANOVA showed a time effect for the triceps skinfold ($F_{(2,24)} = 5.595$, $P = 0.010$) with a specific decrease in skinfold thickness between the under-16 group and under-17 group (12.71 ± 4.09 mm c.f. 10.43 ± 2.98 mm, respectively; $P = 0.001$) and between the under-15 group and under-17 group (12.79 ± 5.48 mm c.f. 10.43 ± 2.98 mm, respectively; $P = 0.048$). There were further time effects present for the thigh skinfold ($F_{(2,24)} = 4.113$, $P = 0.029$) which was attributable to a reduction in skinfold thickness between the under-16 group and under-17 group (19.82 ± 8.03 mm c.f. 16.08 ± 5.66 mm, respectively; $P = 0.038$) and the under-15 group and the under-17 group (18.03 ± 6.74 mm c.f. 16.08 ± 5.66 mm, respectively; $P = 0.038$). No significant time effects were apparent for the bicep skinfold ($F_{(2,24)} = 1.709$, $P = 0.202$), the sub-scapula skinfold ($F_{(2,24)} = 0.564$, $P = 0.576$), the abdominal skinfold ($F_{(2,24)} = 0.731$, $P = 0.492$) and the pectoral skinfold ($F_{(2,24)} = 0.840$, $P = 0.444$).

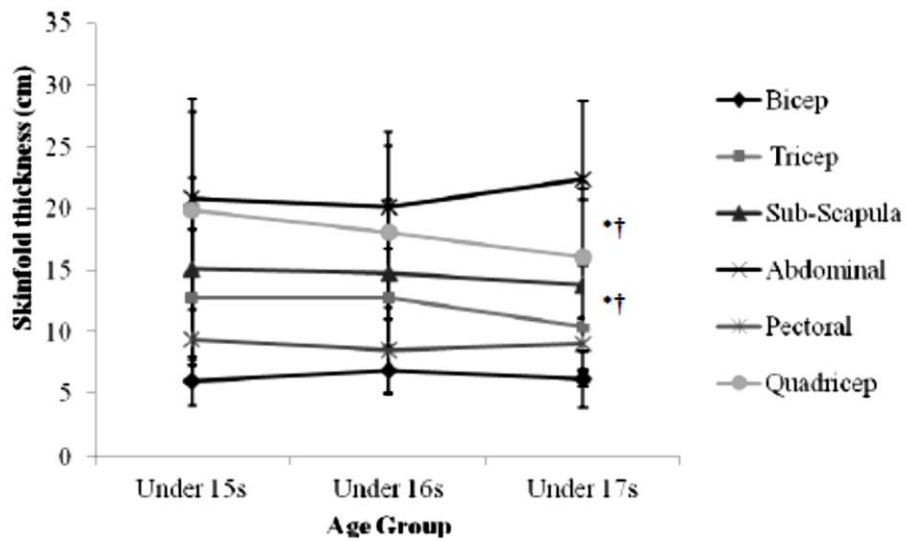


Figure 6.16. Annual data plots for six separate skinfold sites for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group; † = significantly different ($P < 0.05$) to the under-16 group.

The ANOVA demonstrated no changes in the sum of six skinfolds ($F_{(2,24)} = 0.755$, $P = 0.481$) or the predicted percentage of body fat ($F_{(2,24)} = 0.307$, $P = 0.739$) between the age groups (Figure 6.17).

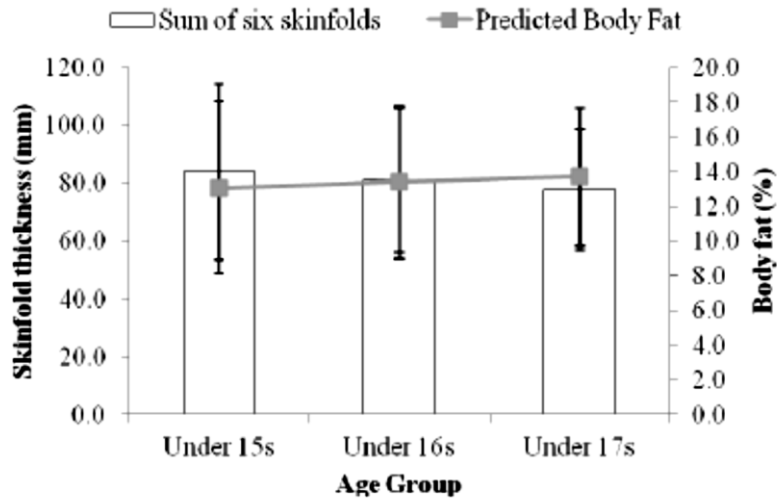


Figure 6.17. Annual data plots for the sum of six skinfold sites and the predicted percentage of body fat for players selected over three successive seasons ($n = 13$).

The maturational age of players increased on an annual basis ($F_{(2,24)} = 100.766$, $P < 0.001$), with differences observed from the under-15 group to -16 group (1.31 ± 5.48 y c.f. 1.73 ± 0.27 y, respectively; $P < 0.001$), followed by the under-16 group to under-17 group (1.73 ± 0.27 c.f. 2.16 ± 0.31 y, respectively; $P < 0.001$) (Figure 6.18). The mean development rates of all anthropometric measurements are presented in Table 6.4.

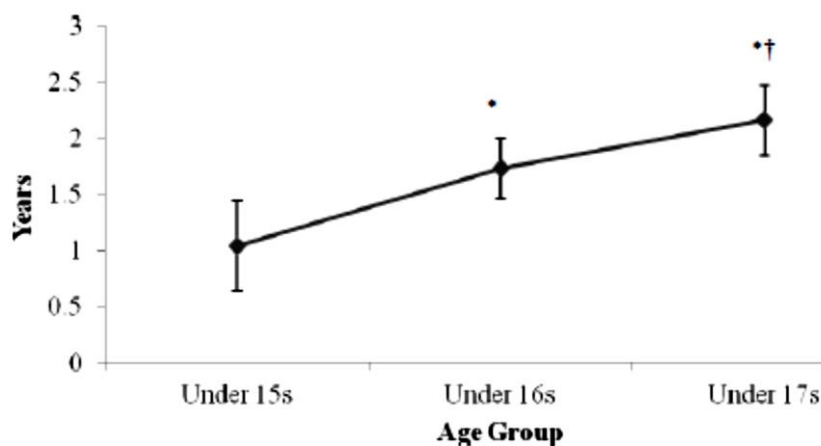


Figure 6.18. Annual data plots for the maturational age (maturity offset value; years) for players selected over three successive seasons ($n = 13$). * = significantly different ($P < 0.05$) to the under-15 group; † = significantly different ($P < 0.05$) to the under-16 group.

Table 6.4. Mean rates of development and percentage changes over successive annual periods in measurements of anthropometry

	Year 1-2 mean rate of change (n·year ⁻¹)	mean %Δ	Year 2-3 mean rate of change (n·year ⁻¹)	mean %Δ
Maturity offset (y)	0.69 ± 0.19	66.62	0.43 ± 0.04	25.03
Body mass (kg)	4.21 ± 9.31	5.14	0.20 ± 9.01	0.23
Lean body mass (%)	0.97 ± 3.69	1.37	2.29 ± 2.25	3.20
Stature (cm)	0.64 ± 0.65	0.36	0.22 ± 0.33	0.12
Seated stature (cm)	1.14 ± 1.12	1.23	0.10 ± 0.28	0.11
Leg length (cm)	0.36 ± 0.44	0.42	-0.23 ± 0.82	0.00
Femur length (cm)	0.38 ± 1.56	2.42	0.06 ± 2.11	0.15
Humerus length (cm)	-0.06 ± 0.64	-0.18	0.08 ± 0.66	0.24
Upper arm circumference (cm)	0.28 ± 2.23	0.85	0.50 ± 1.38	1.47
Quadriceps circumference (cm)	-0.16 ± 2.40	-0.28	1.98 ± 3.03	3.34
Calf circumference (cm)	0.61 ± 1.11	1.58	-0.12 ± 1.34	-0.31
Chest circumference (cm)	0.75 ± 4.05	0.74	2.31 ± 2.47	2.24
Predicted quadriceps CSA (cm²)	12.23 ± 21.46	10.12	21.67 ± 20.13	16.28
Bicep skinfold (mm)	0.83 ± 1.83	13.96	-0.72 ± 1.15	-10.45
Triceps skinfold (mm)	-0.07 ± 2.72	-0.60	-2.84 ± 1.93	-17.97
Chest skinfold (mm)	-0.84 ± 2.67	-9.04	0.53 ± 1.81	6.23
Sub-scapular skinfold (mm)	-0.33 ± 4.86	-2.24	-0.99 ± 2.07	-6.72
Abdominal skinfold (mm)	-0.67 ± 8.73	-3.24	2.21 ± 5.07	10.95
Quadriceps skinfold (mm)	-1.79 ± 4.45	-9.04	-1.96 ± 3.03	-10.92
Sum of 6 skinfolds (mm)	-2.89 ± 19.4	-3.44	-3.22 ± 11.48	-3.97
Body fat (%)	0.34 ± 3.58	2.60	0.33 ± 2.29	2.46

6.3.3 Comparison of performance measures by selection at progressive annual stages in youth rugby league players

For the under-15 group (Table 6.5), independent t -tests showed differences between the selected and unselected players for sprint times over 10 m ($t =_{(19)} -2.237$, $P = 0.039$), 20 m ($t =_{(19)} -2.916$, $P = 0.009$) and 30 m ($t =_{(19)} -3.054$, $P = 0.007$). There were also differences between the groups for peak speed over 30 m ($t =_{(19)} 3.337$, $P = 0.006$), acceleration over 10 m ($t =_{(19)} 2.135$, $P = 0.048$) and 30 m ($t =_{(19)} 3.133$, $P = 0.006$), force over 10 m ($t =_{(19)} 3.555$, $P = 0.001$) and 30 m ($t =_{(19)} 3.855$, $P = 0.003$) and mean power over 10 m ($t =_{(19)} 3.453$, $P = 0.001$) and 30 m ($t =_{(19)} 3.862$, $P = 0.001$). The only non-sprint related variable different between the selected and unselected players in the under-15 age group was CMJ height ($t =_{(19)} 3.107$, $P = 0.048$). When age at PHV was used as a covariate, 10 m sprint time, 30 m peak speed and 10 m acceleration were no longer different between the groups of players ($P > 0.05$).

In the under-16 age group, the selected group demonstrated a higher squat jump height ($t =_{(20)} 2.394$, $P = 0.027$) and predicted vertical power from the counter movement jump ($t =_{(20)} 2.144$, $P = 0.045$), however, the CMJ height was not higher in the selected group ($t =_{(20)} 1.876$, $P = 0.076$) (Table 6.5). In the under-17 group, independent t -tests showed no differences ($P > 0.05$) between the selected and unselected players for any variable (Table 6.5). When PHV was statistically controlled for using ANCOVA, 10 m acceleration was again no longer different between the two groups.

Table 6.5. Comparison of performance measures (mean \pm SD) between selected and unselected rugby league players in the under-15, -16 and -17 age groups.

	Under-15 group		Under-16 group		Under-17 group	
	Selected (n = 16)	Unselected (n = 5)	Selected (n = 14)	Unselected (n = 7)	Selected (n = 9)	Unselected (n = 6)
Predicted $\dot{V}O_{2\max}$ (ml·kg⁻¹·min⁻¹)	48.10 \pm 3.40	47.40 \pm 5.70	49.21 \pm 3.62	46.67 \pm 4.77	52.66 \pm 3.84	52.31 \pm 3.24
10 m mean time (s)	2.13 \pm 0.11*	2.26 \pm 0.13	2.08 \pm 0.13	2.04 \pm 0.10	2.00 \pm 0.40	2.02 \pm 0.05
20 m mean time (s)	3.45 \pm 0.13*†	3.65 \pm 0.18	3.38 \pm 0.18	3.34 \pm 0.14	3.27 \pm 0.07	3.31 \pm 0.08
30 m mean time (s)	4.67 \pm 0.18*†	4.96 \pm 0.27	4.59 \pm 0.23	4.57 \pm 0.22	4.53 \pm 0.13	4.59 \pm 0.12
10 m peak speed (m·s⁻¹)	6.81 \pm 0.45	6.62 \pm 0.26	6.87 \pm 0.39	6.97 \pm 0.43	6.92 \pm 0.47	6.91 \pm 0.32
30 m peak speed (m·s⁻¹)	8.31 \pm 0.34*	7.83 \pm 0.48	8.26 \pm 0.41	8.11 \pm 0.56	8.16 \pm 0.71	8.05 \pm 0.45
10 m acceleration (m·s⁻²)	3.19 \pm 0.32*	2.93 \pm 0.29	3.31 \pm 0.27*	3.42 \pm 0.29	3.45 \pm 0.25	3.41 \pm 0.22
30 m acceleration (m·s⁻²)	1.78 \pm 0.14*†	1.58 \pm 0.17	1.81 \pm 0.15	1.77 \pm 0.20	1.80 \pm 0.20	1.75 \pm 0.11
Force 10 m (N)	245.20 \pm 15.70*†	180.6 \pm 16.90	275.20 \pm 35.81	256.61 \pm 36.11	300.64 \pm 33.51	267.11 \pm 19.10
Force 30 m (N)	137.10 \pm 12.40*†	97.30 \pm 11.10	149.10 \pm 19.11	133.41 \pm 18.11	157.11 \pm 22.61	137.53 \pm 12.4
Mean power 10 m (W)	1152.20 \pm 173.60*†	804.70 \pm 181.11	1324.27 \pm 190.24	1261.92 \pm 225.33	1500.41 \pm 170.51	1317.31 \pm 94.9
Mean power 30 m (W)	883.60 \pm 127.20*†	593.40 \pm 126.70	982.61 \pm 147.16	880.22 \pm 159.22	1040.91 \pm 168.24	898.29 \pm 82.5
CMJ height (cm)	47.00 \pm 3.90*†	41.20 \pm 2.61	47.96 \pm 5.39	41.97 \pm 4.62	49.22 \pm 5.93	45.85 \pm 5.40
Squat jump height (cm)	39.10 \pm 11.50	35.51 \pm 3.92	43.01 \pm 4.50*†	37.15 \pm 4.93	46.62 \pm 5.94	43.10 \pm 5.42
Predicted vertical power (W)	3368.70 \pm 828.50	2582.84 \pm 483.31	4142.22 \pm 425.21*†	3478.24 \pm 416.92	4295.10 \pm 337.91	3921.11 \pm 311.70

Note (for all Tables): * = significantly different ($P < 0.05$) to unselected group; † = significantly different ($P < 0.05$) to unselected group when controlled for maturational age.

6.3.4 Comparison of anthropometric measurements by selection at progressive annual stages in youth rugby league players

As presented in Table 6.6, at the under-15 group, independent t -tests showed differences between the selected and unselected players for age at PHV ($t =_{(19)} -2.291$, $P = 0.039$), body mass ($t =_{(19)} 2.253$, $P = 0.036$) lean body mass ($t =_{(19)} 2.272$, $P = 0.035$), and bicep circumference ($t =_{(19)} 2.291$, $P = 0.034$). In the under-16 group, only quadriceps circumference was shown to be larger in selected players ($t =_{(19)} 2.248$, $P = 0.037$). There were no differences ($P > 0.05$) between selected and unselected players for any of the anthropometric measurements in the under-17 age group (Table 6.6).

Table 6.6. Comparison of anthropometric measurements (mean \pm SD) between selected and unselected rugby league players in the Under-15, -16 and -17 age groups.

	Under-15 group		Under-16 group		Under-17 group	
	Selected (<i>n</i> = 16)	Unselected (<i>n</i> = 5)	Selected (<i>n</i> = 14)	Unselected (<i>n</i> = 7)	Selected (<i>n</i> = 9)	Unselected (<i>n</i> = 6)
Chronological Age (y)	15.11 \pm 0.31	15.01 \pm 0.39	16.25 \pm 0.28	16.20 \pm 0.39	17.00 \pm 0.29	17.04 \pm 0.29
Age at PHV (y)	14.12 \pm 0.32	14.48 \pm 0.54*	14.54 \pm 0.34	14.91 \pm 0.65	14.74 \pm 0.39	14.97 \pm 0.42
Maturity Offset (y)	0.95 \pm 0.28	0.54 \pm 0.51	1.71 \pm 0.27	1.28 \pm 0.62	2.52 \pm 0.29	2.07 \pm 0.37
Body Mass (kg)	83.31 \pm 8.90	75.11 \pm 8.10*	83.22 \pm 8.32	78.24 \pm 9.19	88.67 \pm 9.73	82.83 \pm 8.97
Lean Body Mass (%)	70.62 \pm 6.10	65.70 \pm 5.92*	71.59 \pm 5.62	68.17 \pm 7.41	75.22 \pm 6.21	72.83 \pm 6.89
Stature (cm)	180.23 \pm 4.40	177.41 \pm 2.11	179.89 \pm 4.32	178.22 \pm 2.49	180.11 \pm 4.34	181.06 \pm 4.75
Seated Stature (cm)	93.75 \pm 2.0	90.98 \pm 3.61	94.4 \pm 21.97	91.61 \pm 4.28	95.32 \pm 2.19	93.98 \pm 2.55
Leg Length (cm)	86.42 \pm 3.60	86.41 \pm 3.42	85.49 \pm 3.94	86.62 \pm 3.71	84.77 \pm 3.23	87.08 \pm 4.20
Femur Length (cm)	45.43 \pm 2.51	44.53 \pm 1.92	44.95 \pm 1.89	45.51 \pm 2.28	44.23 \pm 2.22	17.04 \pm 0.29
Humerus Length (cm)	35.11 \pm 1.21	34.42 \pm 1.26	34.76 \pm 1.21	34.65 \pm 1.72	35.01 \pm 1.46	34.91 \pm 1.47
Bicep Circumference (cm)	33.86 \pm 1.92	29.94 \pm 9.90*	33.81 \pm 2.52	32.35 \pm 4.68	35.04 \pm 2.35	33.11 \pm 2.12
Quadriceps Circumference (cm)	58.43 \pm 4.21	52.91 \pm 5.31	57.90 \pm 4.23	53.54 \pm 6.07*	61.01 \pm 4.61	57.56 \pm 3.31
Calf Circumference (cm)	38.71 \pm 2.72	36.52 \pm 2.22	38.95 \pm 2.71	37.17 \pm 2.58	37.91 \pm 2.22	39.72 \pm 3.12
Chest Circumference (cm)	103.22 \pm 5.51	98.55 \pm 6.16	102.85 \pm 6.01	100.48 \pm 6.55	107.27 \pm 4.28	102.98 \pm 6.22
Predicted Quadriceps CSA (cm²)	116.31 \pm 41.60	124.43 \pm 35.13	132.39 \pm 34.71	128.72 \pm 39.72	148.69 \pm 30.17	160.75 \pm 19.95
Bicep Skinfold (mm)	6.01 \pm 2.22	6.43 \pm 3.21	6.80 \pm 2.01	6.54 \pm 3.43	6.08 \pm 1.99	6.63 \pm 1.76
Triceps Skinfold (mm)	13.24 \pm 5.71	10.51 \pm 5.01	12.69 \pm 3.93	10.07 \pm 5.41	10.78 \pm 3.34	10.50 \pm 2.19
Sub-scapular Skinfold (mm)	15.85 \pm 7.71	13.64 \pm 6.71	14.71 \pm 4.81	14.34 \pm 8.48	14.68 \pm 4.52	14.71 \pm 4.81
Pectoral Skinfold (mm)	9.71 \pm 3.24	9.26 \pm 3.16	8.55 \pm 2.55	9.57 \pm 2.86	9.47 \pm 2.72	8.08 \pm 2.05
Abdominal Skinfold (mm)	21.05 \pm 7.81	18.21 \pm 7.54	20.34 \pm 7.39	19.22 \pm 7.77	23.99 \pm 6.41	19.61 \pm 6.49
Quadriceps Skinfold (mm)	20.92 \pm 8.22	15.77 \pm 4.41	18.11 \pm 6.48	15.48 \pm 5.03	17.91 \pm 5.89	13.44 \pm 2.65
Sum of 6 Skinfolks (mm)	87.65 \pm 31.12	73.82 \pm 25.80	81.15 \pm 24.02	75.24 \pm 24.02	82.84 \pm 20.99	70.56 \pm 14.90
Body Fat (%)	14.87 \pm 4.91	12.20 \pm 4.12	13.49 \pm 4.26	12.71 \pm 4.01	14.85 \pm 3.78	11.91 \pm 2.91

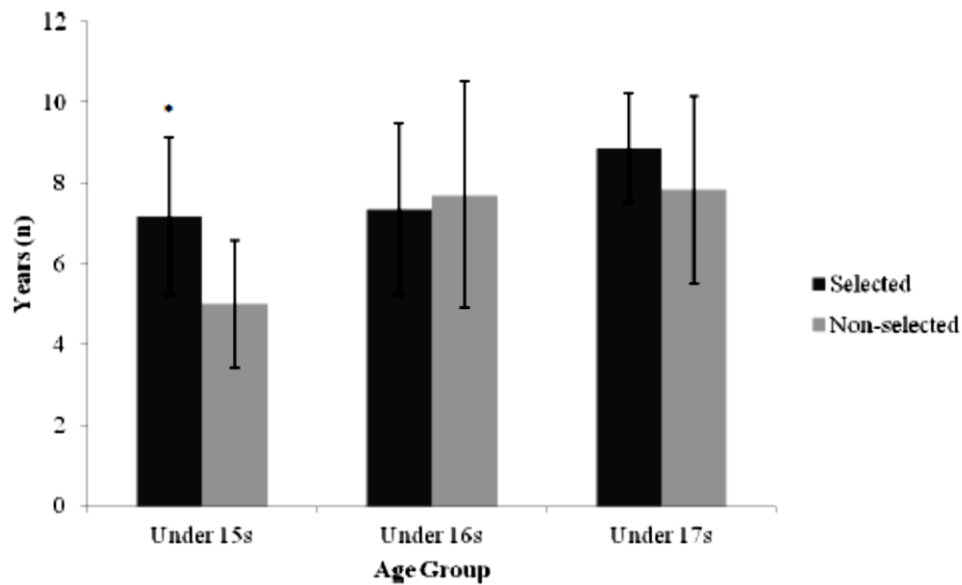


Figure 6.19. A comparison of selected and unselected players' years of formal playing experience during the under-15 group, -16 and -17 age groups. * = significantly different ($P < 0.05$) to the non-selected group.

Independent t -tests revealed differences in formal playing experience between the selected (7.18 ± 1.97 years) and unselected (5.01 ± 1.58 years) players among the under-15 age group ($t =_{(19)} 2.250$, $P = 0.037$). No other differences ($P > 0.05$) were apparent between selected and unselected players in any group for formal playing experience (Figure 6.19).

In the under-15 group, a stepwise discriminant function analysis identified 30 m force as the only predictor (1) of group selection ($P = 0.001$). This variable was able to correctly classify 87.5% of the selected players and 80% of the unselected players, explaining 47.3% (canonical coefficient = 0.658) of the between-group variability. The discriminant function was altered in the under-16 group, whereby a combination of squat jump height (0.692) and 10 m acceleration (-0.388) were shown to explain 40.7% of the overall group variance ($P = 0.009$; canonical coefficient = 0.638), correctly classifying 92.9% of selected players and 71.4% of unselected players (Table 6.7).

Table 6.7. Summary of the stepwise discriminant function analyses by selection status (selected vs. unselected)

		Variables Entered/Removed							
		Wilks' Lambda							
		Exact F							
	Entered	Statistic	df1	df2	df3	Statistic	df1	df2	Sig.
Step	Under-15								
	group								
1	30 m Force	0.568	1	1	19.000	14.478	1	19.000	0.001
	Under-16								
	group								
1	Squat Jump Height	0.753	1	1	19.000	6.247	1	19.000	0.022
2	10 m Acceleration	0.593	2	1	19.000	6.183	2	18.000	0.009
	Under-17								
	group								
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Note: At each step, the variable that minimizes the overall Wilks' Lambda is entered. Maximum number of steps is 80; Maximum significance of F to enter is $P = 0.05$; Minimum significance of F to remove is 0.10.; F level, tolerance or VIN insufficient for further computation.

6.3.5 Relationship between anthropometry and performance measures in rugby league players by age group

In the under-15 group, amongst other relationships that can be seen in Table 6.8, the anthropometric predictor variables of maturational age ($r = 0.523$, $P = 0.015$), years of experience ($r = 0.475$, $P = 0.030$) or lean body mass ($r = 0.584$, $P = 0.005$) were significantly related to force generated over 30 m. Force over 30 m was identified as the single most important predictor of selected players in the previous stepwise discriminant function analysis among the under-15 group. Other performance variables such as 20 m sprint time ($r = 0.562$, $P = 0.008$) and predicted vertical jump power ($r = 0.524$, $P = 0.015$) were also related to years of experience and maturational age, respectively (Table 6.8). In the under-16 group, maturity age and lean body mass was related to 10 m force ($r = -0.638$, $P = 0.002$ and $r = 0.774$, $P = 0.001$, respectively), 30 m force ($r = -0.593$, $P = 0.006$ and $r = 0.810$, $P < 0.001$, respectively) and vertical power ($r = -0.637$, $P = 0.001$ and $r = 0.685$, $P = 0.001$, respectively). However, there was no relationship between performance and years of experience in the under-16 group ($P < 0.05$). The same trend was also apparent during the under-17 age group, with maturity age and lean body mass significantly relating to 10 m force ($r = -0.727$, $P = 0.002$ and $r = 0.734$, $P = 0.002$, respectively), 30 m force ($r = -0.609$, $P = 0.016$ and $r = 0.578$, $P < 0.024$, respectively) and vertical jump power ($r = -0.688$, $P = 0.005$ and $r = 0.658$, $P = 0.005$, respectively). Whilst other significant relationships were apparent, the strength of the relationship either did not reach a 'large' magnitude ($r > 0.5$) or did not demonstrate the consistency of maturity age and lean body mass in predicting performance measures.

Table. 6.8. Correlation matrix of maturity, years of experience, quadriceps muscle CSA and lean body mass and selected performance variables.

		Pearson Correlation Coefficient <i>r</i> (<i>P</i> -value)			
		Maturity Age (y)	Years of Experience (y)	Quadriceps CSA (cm ²)	Lean Body Mass (%)
Under-15 group (<i>n</i> = 21)	10 m force (N)	-.457 (.037)*	.451 (.035)*	.075 (.746)	.605 (.004)*
	30 m force (N)	.523 (.015)*	.475 (.030)*	-.014(.953)	.584(.005)*
	20 m Sprint time (s)	.182(.430)	.562(.008)*	.075(.746)	-.127(.583)
	CMJ (cm)	.115(.619)	.201(.382)	.131(.570)	.243(.289)
	Predicted Vertical Power (W)	.524 (.015)*	-.015 (.950)	.109 (.637)	.515 (.017)*
	Squat Jump (cm)	-.340 (.131)	-.179 (.437)	.290 (.203)	.237 (.301)
Under-16 group (<i>n</i> = 21)	10 m force (N)	-.638 (.002)*	.314 (.165)	.076 (.743)	.774 (.001)*
	30 m force (N)	-.593 (.006)*	.279 (.220)	.324 (.152)	.810 (.000)*
	20 m Sprint time (s)	.005 (.984)	-.204 (.375)	-.607 (.003)*	-.126 (.526)
	CMJ (cm)	.287 (.207)	.245 (.285)	.136 (.558)	.261 (.253)
	Predicted Vertical Power (W)	-.637 (.001)*	.306 (.179)	-.076 (.773)	.685 (.001)*
	Squat Jump (cm)	-.297(.192)	.356 (.113)	.079 (.773)	.227 (.323)
Under-17 group (<i>n</i> = 15)	10 m force (N)	-.727 (.002)*	.016 (.995)	.023 (.936)	.734 (.002)*
	30 m force (N)	-.609 (.016)*	.019 (.947)	.109 (.698)	.578 (.024)*
	20 m Sprint time (s)	.057 (.841)	-.364 (.182)	-.042 (.882)	.157 (.576)
	CMJ (cm)	.012 (.965)	-.113 (.689)	.030 (.914)	-.084 (.765)
	Predicted Vertical Power (W)	-.688 (.005)*	.045 (.873)	-.171 (.543)	-.658 (.008)*
	Squat Jump (cm)	.014(.960)	.110 (.695)	.020 (.942)	-.086 (.760)

Note: * = significant relationship between corresponding matrix factor. *R* value relationship; 0 = No relationship; < 0.1 = weak; < 0.2 = small; < 0.3 = moderate; > 0.5 = strong (Cohen, 1992).

6.4 Discussion

The initial aim of the current longitudinal study was to identify the rate of development in physical performance and anthropometric dimensions amongst young rugby league players who competed within each of the three successive year groups. As such, this study has identified a period between the under-15 and the under-16 age groups in which the greatest improvements in physical performance were observed. Such improvements were demonstrated by reductions in sprinting time over 10, 20 and 30 m intervals and concomitant increases in the force and power developed over 10 and 30 m. The largest mean changes occurred in the sprint-related variables measured over 10 m, represented by a 5% increase (faster) in 10 m sprint time, a 13.9% increase in 10 m force development and a 19.8% increase in 10 m power. These changes are equivalent to first year annual development rates of 0.10 s per year, 31.3 N per year and 116 W per year, respectively. Interestingly, between the under-16 and -17 age groups (later period), these development rates were not observed, with no differences between these year groups for any performance variables apart from an 8.2% improvement in predicted $\dot{V}O_{2\max}$. At a fundamental level, it is important for rugby league practitioners to understand that players will develop their aerobic and anaerobic fitness capabilities at different rates during later adolescence. This is demonstrated by a marked increase in muscle power and speed at younger ages, followed at the final stage (of the current study) by a plateau in development, characterized only by an isolated rise in MSFT performance.

The larger improvements between the under-15 and under-16 age groups in functional tests of performance should be expected owing to the anticipated rate of physical growth at this stage of maturity (Buenen & Malina, 1988). Players within the under-15 group were

approximately one year post peak height velocity (PHV); a period which has been associated with significant increases in serum testosterone over six month intervals and a concomitant increase in stature, body mass and testicular volume (Vantinen et al., 2011; Hansen & Klausen, 2004). Such large increases in circulating growth androgens, such as testosterone and dihydrotestosterone, are related to nitrogen retention at tissue level and subsequent muscular development, resulting in increased functional performance in the years after the onset of puberty (Baldari et al., 2009; Gravina et al., 2008; Hansen et al., 1999a; 1999b). Whilst limited by their cross-sectional design, research with regional standard rugby league players has also shown differences in short explosive movements, such as vertical jumping (4.8% to 17.8%; Till et al., 2011; Gabbett, 2009; 2002) and 10 m sprint performance (1.6% to 2.7%; Till et al., 2011; Gabbett, 2009; 2002) between the earlier ages of either 14 to 15 and 15 to 16 years. In accordance with the current findings, reports from Australia have shown no change in any parameter of performance (speed, agility, aerobic capacity) between the later ages of 16 and 18 (Gabbett, 2009; 2002). However, whilst previous studies have provided some evidence of the expected performance norms amongst youth rugby league players in Australia and the UK, they provide no indication of the expected development rates over successive periods of later adolescence. Indeed, few studies have been designed to span the period of later adolescence (leading to adult transitions) which offers practitioners preliminary evidence of ‘what’ and ‘when’ to expect development in field-based measures of physical capacity that can be easily and reliably administered (see Chapter 3). As such, the continual use of such measures would be beneficial to clubs wishing to monitor the changes in performance across age group progressions and can be used as a guide for talent development. Moreover, given the evidence available to support muscular adaptation during the post-pubertal years in response to resistance (Gorostiga et al., 1999; Hansen et al., 1999b) and aerobic training (Baxter-Jones et al., 2003; 1993), a pragmatic approach to talent

development in rugby league would be to monitor seasonal changes in performance in accordance with different training stages. Indeed, the current cohort regularly engaged in various training practices that were designed to enhance sport-specific qualities, such as small-sides conditioning games. However, the value of these programmes has yet to be evaluated in British-based rugby league players.

Research in other team sports, such as the five-year Ghent Youth Soccer Project (GYSP), has demonstrated the expected rates of performance development in adolescent male soccer players to peak at PHV, followed by a plateau in the subsequent two years (Philippaerts et al., 2006). For example, the highest rate of improvement in running speed in a 30 m sprint ($-0.4 \text{ s}\cdot\text{year}^{-1}$) and CMJ ($5 \text{ cm}\cdot\text{year}^{-1}$) peaked in accordance with PHV, highlighting the common assumption that physical growth and performance are related (Boisseau & Delmarche, 2000). Philippaerts and colleagues (2006) also showed that, in the 6 and 12 months after PHV, the rate of improvement in the 30 m sprint and CMJ was reduced to $-0.3 \text{ s}\cdot\text{year}^{-1}$ and $-0.2 \text{ s}\cdot\text{year}^{-1}$ and $3.8 \text{ cm}\cdot\text{year}^{-1}$ and $3.3 \text{ cm}\cdot\text{year}^{-1}$, respectively. The rates at which improvement occurred in the above studies are somewhat larger than those of the current rugby league cohort, despite a similar trend in performance. For example, compared to data reported by Philippaerts et al. (2006), the current cohort experienced smaller improvements in 30 m sprint times between the under-15 group and -16 group ($-0.14 \text{ s}\cdot\text{year}^{-1}$) and under-16 group and -17 group ($0.01 \text{ s}\cdot\text{year}^{-1}$). Likewise, smaller improvements in CMJ height were demonstrated between successive years, equating to $0.27 \text{ cm}\cdot\text{year}^{-1}$ and $0.33 \text{ cm}\cdot\text{year}^{-1}$ between the under-15 group and 16 and the under-16 group and 17, respectively. These findings are likely to be explained by the comparatively advanced biological maturity of the current sample in which the initial assessments were recorded at one year post-PHV. Nevertheless, these results show

that it would be inappropriate to generalize the expected development patterns of youth players from different sports.

The developments in force and power generation over 10 m represented the largest changes in performance for the cohort of players in this study. Given the small degree of error apparent in GPS peak speed measurements that are used to derive acceleration data (peak speed CV = 0.78%; see Chapter 3), systematic improvements of 19% and 5% between successive age group transitions can be easily identified. The capacity to reliably use field-based measuring equipment to detect changes in seemingly important performance parameters is useful for rugby league practitioners. Previous studies have demonstrated the value in performing tests that account for the interaction between body mass and movement rates when evaluating sprint performance (Comfort et al., 2011; Baker & Newton, 2008). For example, Baker and Newton (2008) showed that 10 m sprint momentum (velocity \times body mass) can discern between top division adult professional rugby league players (National Rugby League; NRL) and players of the second division (State Rugby League; SRL), whereas absolute speed over 10 m, 20 m and 30 m did not. The reasons for this are likely to be related to the demands of the rugby league game (see Chapter 7), whereby players are often involved in one-on-one collisions either as the ball carrier or whilst tackling the ball carrier. The 10 m rule in rugby league compels players to retreat from the gain line at the conclusion of each phase of play, thus creating at least a 10 m space in which to generate speed prior to making contact with opposing players. Therefore, it is beneficial for players to develop ways in which to create momentum (i.e. force and power). Indeed, the concept of relative force and power as a valuable determinant of playing ability is becoming commonplace amongst rugby league researchers (Comfort et al., 2011; Gabbett et al., 2008a). This is the first study to observe developments in relative measures (i.e. relative to body

mass) of sprint performance in youth rugby league players during the adolescence to adult transition. These findings should encourage rugby league practitioners to consider the optimal balance of gains in body mass with gains in over-ground speed in youth players, in order to achieve the sport-specific requirement for short-term force and power generation.

In support of the above findings, the current research has shown no changes in peak speed over both 10 m and 30 m or acceleration over 30 m throughout the entire study period. In relation to the findings presented in Chapter 7 of the current thesis, where the average sprint distance during a match was approximately 10 m, it is logical to expect players' sprint capabilities and developments to mirror the demands of the competitive game. Furthermore, the current cohort regularly undertook specific high-intensity interval training which was tailored to meet sport-specific requirements (i.e. sprinting over the distances of 10 m to 20 m) which may have induced an additional training effect. Sustained bouts of repeated-sprint intervention with young soccer players has been shown to induce 'test-specific changes' in isolated linear sprint speed (Buchheit et al., 2012a). These changes are likely to be the result of neuromuscular adaptations, such as an enhanced neural firing rate as well as changes in both qualitative and quantitative muscle fibre recruitment patterns (Spiering et al., 2008). Such developments have not been documented in youth rugby league players but would be useful to understand since little is known regarding the correct training methods to adopt in order to develop the appropriate performance markers in such athletes. Furthermore, there is no documented evidence to inform youth rugby league practitioners of the most appropriate methods with which to improve functional force and power during over-ground sprinting. According to research in other team sports, this may be enhanced through neuromuscular orientated training practices, such as plyometrics (Johnson et al., 2011; Thomas et al., 2009;

Kotzamanidis, 2006), explosive resistance training (Ingle et al., 2006) and programmes focussed on changes of direction at speed (COD) (Buchheit et al., 2008).

An important development between the under-15 and under-16 groups appears to be the predicted power output from the vertical jump performance. This was not the case with absolute values for squat or countermovement jumping, which have been reported as predictors of selection in other related sports such as Australian Football (Keogh, 1999). Predicted vertical power represents an additional dimension of relative short-term, power output and supports the previous assertion that gains in lower-limb power development should be considered in accordance with concomitant developments in fat-free, propulsive mass. Such results, coupled with the findings related to force and power production whilst sprinting, may indicate the scope to apply 'ratio' techniques during talent identification procedures. That is, the assessment of performance measures in relation to anthropometric variables such as body mass and stature (Crewther et al., 2011). Such an approach would be an interesting future direction in order to understand the development in jump performance and power in relation to body dimensions amongst players undergoing maturity.

This is the first study to evaluate the longitudinal development of anthropometric characteristics amongst youth rugby league players during later adolescence. Over the three year period, players developed from 1.04 years to 1.73 years, through to 2.16 years post PHV. This coincided with an increase in stature, seated stature and femur length during the first transitional period, followed by a lagged increase in quadriceps circumference, chest circumference and lean body mass and predicted muscle CSA of the quadriceps among the under-16 to under-17 age groups. It should be noted that changes in leg length were not apparent in the current study, even in the presence of changes in femur length. Logically,

such findings were unanticipated and are likely to relate to the associated measurement error noted in the Methods section. The biological events that occur during the post-pubertal years are complex and include changes in the nervous and endocrine systems that, in turn, coordinate anthropometric and physiological alterations (Tanner, 1962) as observed in the current study. The observed patterns, which showed a change in various indications of bone length (stature, seated stature and femur length) during post-PHV stages, are consistent with the normal male growth curves presented by previous authors (Anderson & Twist, 2005; Jolicuer et al., 1988; Tanner & Whitehouse, 1976) and represent the anticipated slowing of growth velocity during later teenage years (Rogol, 2004). However, the initial age (~ 14.5 years) of the current participants was marginally greater (~1-2 y) compared to the starting age reported within previous longitudinal or cross-sectional rugby league studies (Till et al., 2011; Gabbett, 2009) or other team-based sports (see Huijgen et al., 2009; Philippaerts et al., 2006), thereby increasing the likelihood of advanced biological maturity. Indeed, the height velocity demonstrated between the under-15, -16 and -17 age groups (mean change < 1 cm·year⁻¹) was much smaller than expected for players in comparable age ranges in hockey (approximately 5 cm·year⁻¹; Elferink-Gemser et al., 2006) and soccer (approximately 5 cm·year⁻¹; Philippaerts et al., 2006). This is perhaps related to the later initial measurement of stature which was approximately 3 cm larger than previous reports (see above), coupled with the relatively young maturational age of the repeated measures cohort (13.8 years) compared to some previous studies (Bell, 1993; Forberg et al., 1991). At a fundamental level, this is further evidence of relatively earlier biological maturity amongst ‘selected players’ in British-based youth rugby league (Till et al., 2010).

Aside from stature, the general growth patterns in anthropometric components observed in the current study are comparable to normal growth standards and expected rates of

development (Jolicuer et al., 1988). For example, the body mass of the rugby league cohort was 81.8 kg and developed at a rate of $4.2 \text{ kg}\cdot\text{year}^{-1}$ at the first transitional stage, which matches the rate reported in previous longitudinal studies but highlights the superior mass of rugby league players compared to that of normal populations ($\sim 60 - 67 \text{ kg}$; Tanner & Whitehouse, 1976; Taylor et al., 2010) or samples of soccer ($\sim 58 \text{ kg}$; Malina et al., 2004), hockey (58 kg; Elferink-Gemser et al., 2006) and basketball players ($\sim 67 \text{ kg}$; Coehlo e Silva et al., 2008) of the same chronological age. Notwithstanding the discrepancies between different skinfold sites and body composition estimations, the body fat percentage and sum of six skinfolds in the current study was also similar to previous research (Till et al., 2010; Gabbett et al., 2008a). Therefore, the most logical mechanisms accounting for such similarities in body mass velocity between the age groups of the under-15 group and -16 group may be related to changes in fat-free mass dimensions. The aforementioned early maturation stage (PHV = 13.8 years) of the three-year cohort would promote premature gains in muscle mass owing to the expected rise in circulating androgens, leading to increases in limb girth and total body mass. Indeed, changes in quadriceps and chest circumference are also consistent with training-induced adaptations and were likely related to the annually-phased resistance training programmes undertaken by the players. The training of the current cohort consisted of specific hypertrophy cycles during non-competitive stages, similar to programmes that develop muscle CSA with participants of this type (Gorostiga et al., 1999). A gain in lean body mass is also expected in normal adolescents as a rise in growth hormone would enhance the synthesis of protein through increased nitrogen retention (Malina et al., 2004) and stimulate hormone-sensitive lipase, thus mobilizing free fatty acids from adipose tissue for energy (Gilbert & Stokes, 2008). The large gains from 71.8% to 74.1% in fat-free mass (2.3% increase) over later adolescence in Scholarship rugby league players develops at a rate beyond that in other sports, such as soccer, where less than a 1% change in fat-free

mass has been reported between the same age groups (Vantinen et al., 2011; Huijgen et al., 2010). These findings have relevance for rugby league practitioners and show that increases in quadriceps muscle CSA, upper arm circumference and, consequently, both fat and lean body mass distinguishes young rugby league players from other team sports players.

The 8% increase in predicted $\dot{V}O_{2\max}$ between the under-16 and -17 age groups was unexpected. This is because measurements of $\dot{V}O_{2\text{peak}}$ during childhood generally increase in direct proportion to changes in body size (Armstrong & Welsman, 1994), detectable only when expressed in absolute terms (Baxter-Jones et al., 1993). However, the use of the MSFT to predict $\dot{V}O_{2\max}$ in the current study represents a measure of ‘performance’ change rather than direct development in aerobic power. Indeed, alterations in muscle-tendon stiffness and improvements in running economy with maturation may improve performance on such tests in junior team sports players (Helgerud et al., 2001). Nevertheless, the current findings provide evidence of the time-point that improvements in shuttle running performance can be expected and are similar to data published on elite field hockey players of the same age group (Elferink-Gemser et al., 2006). Indeed, amongst adolescent boys, changes in absolute $\dot{V}O_{2\max}$ continue into later adolescence (Bar-Or & Rowland, 2004; Baxter-Jones et al., 1993), which is often attributed to (amongst changes in muscle morphology and metabolic processes; Whipp, 1997) concurrent increases in fat-free mass, as observed herein. The period between the under-16 and -17 age groups may also indicate a development towards more adult-like autonomous motor coordination patterns, thus enhancing parameters of general fitness such as running economy and agility which have been shown to improve between adolescence and adulthood (Schepens et al., 2004; De Jaeger et al., 2001).

One possible limitation of the current project is the absence of a repeated sprint (RS) protocol (i.e. Psotta & Bunc, 2003; Rebelo et al., 1998) given its importance in rugby league (Gabbett et al., 2011a). Repeated sprint protocols are useful since they aim to assess the interaction between anaerobic and aerobic energy provision (Svensson & Drust, 2005). Such a test may have provided a more sport-specific indication of maximal over-ground speed and, more importantly, changes in the rate at which fatigue occurs in rugby league players as a function of age. Fatigue resistance is lower in children owing to a greater proportion of type I muscle fibres, lowered phosphofructokinase (PFK) activity and reduced reliance on anaerobic metabolism (Dipla et al., 2009; Ratel et al., 2006). Therefore, an understanding of such developments in rugby league players nearing adulthood would provide an indication of repeated-sprint capability alongside capacity tests such as the 20 m MSFT. Tolerance of fatigue under repeated maximal efforts is important since certain players, such as interchange forwards, competing for briefer match periods have been shown to adopt ‘all-out’ pacing strategies and perform at relatively higher intensities than ‘non-interchange’ players in adult rugby league (Waldron et al., 2012). Coupled with the imminent changes in the interchange rule, reducing the amount of possible interchanges from 12 to 10 or 12 to 8 (RFL, 2012) within adult and youth (< under 18) matches respectively; the ability to withstand fatigue whilst producing repeated sprint efforts could become an important characteristic of rugby league players. However, the exclusion of RS fatigue index assessments from the current study may also be warranted given the reliability and validity of RS protocols which are often questionable owing to factors such as pacing (Svensson & Drust, 2005). Furthermore, a mixture of maximal aerobic speed and peak sprinting speed over-ground will predict 88% of repeated sprint ability (Buchheit, 2012b). Whilst this is yet to be confirmed amongst adolescent players undergoing changes in performance parameters, tests of maximal aerobic

speed (MSFT) and maximal linear sprinting have been carried out in the current study and might provide an indirect indication of RS ability.

A novel aspect of the current project was its ability to monitor the relationship between anthropometric and experience-related variables with markers of performance at each successive year group. An analysis of all available players at each age group showed significant relationships between the factors of either maturational age and lean body mass against force and power generation over 10 m and 30 m and predicted vertical jump power output. These relationships are consistent with changes in peak explosive power which may be developed from an increase in type II muscle fibre composition and neuromuscular firing patterns (amongst other factors) as a function of biological maturity (Ratel et al., 2003; Armstrong et al., 2001). Furthermore, the relationship between quadriceps muscle CSA and 20 m sprint performance in the under-16 group highlights the intimate relationship between muscle volume and anaerobic performance markers at post-pubertal stages (Bar-Or & Rowland, 2004; Duche et al., 1992). Indeed, cross-sectional muscle area is dictated by the number of sarcomeres arranged in parallel, which, in turn, is related to the force production of the muscle (Armstrong et al., 2001). The increase in quadriceps CSA (as above), and subsequent volume of sarcomeres in series increases the time available for actin and myosin interaction, thus increasing the force and eventual power production of the muscle during shortening sequences (Armstrong et al., 2000). The findings of the current study indicate that increases in lean body mass are related to force and power development in young rugby league players. It is likely that these relationships reflect of the sport-specific requirement of rugby league players to develop forward-motion. Interestingly, the relationships found between force generation or vertical power against years of experience at the under-15 group level, did not persist among later age groups. Given that years of playing experience

systematically increased by approximately one year at each measurement point, the reasons for a disproportionate increase in force and power are unclear.

Whilst there were improvements in lean body mass and quadriceps muscle CSA in the repeated measures group ($n = 13$), a slower rate of development in most performance markers was observed in comparison to the initial transition years. Although this trend typifies players of the under-17 group, the performance and physical attributes of these players remains inferior to that of elite adult groups (see Gabbett, 2002). This indicates the potential for further physical and performance developments beyond under-17 group, which is consistent with reports from sports such as team handball, weight lifting and road cycling (see Izquerido et al., 2002). This slowed rate of development might be explained by the stepwise discriminant function analysis, which showed inconsistent annual patterns. For example, force over 30 m (under-15 group) or a combination of squat jump height and 10 m acceleration (under-16 group) discriminated between selected or unselected players, with no differences in any performance parameter or anthropometrical variable in the under-17 group. Whilst this finding could reflect a limitation of a case study approach whereby more homogenous group sets may exist, it appears to signify a phenomenon particular to rugby league in which players often become less discriminable based on growth and performance factors as a function of age. For example, using a cross-sectional research design, Gabbett (2002) has reported differences in various aerobic and anaerobic fitness parameters between starters and non-starters in the under-14 and -16 age groups, followed by no differences among the under-18 age group. The reasons for this similarity between studies may relate to the refinement in selection process, whereby a smaller number of players must be selected at older age groups. Coupled with the evidence that the rate of physical and performance development is slowed towards older age groups, it is also possible that players who were

previously deficient in certain areas of growth and performance are also permitted additional time to reduce such deficits (see Vandendriessche et al., 2012). Such evidence would also support the view that de-selection from talent development programmes based solely on performance at earlier ages is an erroneous practice (Vaeyens et al., 2008).

The current results have clear implications for the appropriate development of young rugby league players since it appears that physically advanced players are preferentially selected at younger ages. This finding is consistent with reports in other team sports (Sherar et al., 2007; Malina et al., 2000), and indicates that rugby league is a physically biased sport. Owing to the relationship between age at PHV and performance, as indicated in the current study, statistical control for maturational age should be considered (Till et al., 2011; Le Gall et al., 2010; Vaeyens et al., 2006). Accordingly, the current study showed the removal of 10 m sprint time, 30 m peak speed and 10 m acceleration (under-15 group) and 10 m acceleration (under-16 group) when age at PHV was entered as a covariate. It is useful to gain an understanding of which factors differentiate between selected and unselected players in both absolute terms and under statistical control for maturity, particularly at later adolescence where selectors are often compelled to make decisions based upon current performance. However, this is the first evidence that maturity is responsible for the removal of factors such as 10 m acceleration (most commonly) amongst rugby league players at younger ages and that other factors such as force and power generation, may be used as predictors of selection independent of the effects of advanced maturation. That being said, the limited ability to discern between players who are selected or unselected in the under-18 age group based on physical size and performance remains a question to address.

Whilst there were no differences found between the selected and unselected players among the oldest age group (under-18), one should also consider coach-selection only as a proxy measure of higher and lower ability in the context of the current case study. That is, whilst this study provides an indication of the factors that determine higher ability, the selection of players is a subjective process. As such, the factors that have been shown to associate with selected players in the current case study might be a reflection of the club's philosophy and may not be consistent across other clubs. Practitioners should also remain aware of the value of certain performance parameters, such as aerobic capacity, despite their failure to differentiate between players at any annual stage. Indeed, given the predominant usage of aerobic metabolism during matches (Coutts et al., 2003), a well-developed aerobic capacity would appear important in rugby league players. Furthermore, aerobic capacity of the current cohort was larger than reported amongst untrained subjects (Chatterjee et al., 2008) and comparable to Australian rugby league players of the same age (Gabbett, 2009). Coaches should, therefore, remain cognisant of the multi-dimensional nature of rugby league and use the current evidence to prioritise training practices and guide the selection process at stages where current performance must be considered.

Like other governing bodies, the Rugby Football League (RFL), have adopted the Long Term Athlete Development (LTAD) (Balyi & Hamilton, 2004), as a method of identifying and developing talented players in accordance with their physical maturity. According to the main proponents of the LTAD (Balyi & Hamilton, 2004), the sport of rugby league qualifies as a 'late specialization' sport, ostensibly meaning that players are not required to reach a theoretical 'peak' in their performance until adulthood (Balyi & Hamilton, 2004). However, it is common for an adult Super League team to regularly field up to six players between the ages of 16 and 19 years (Twist et al, unpublished observations). Such evidence indicates the

need for early identification of players for exposure to Super League competition and questions the LTAD definition of 'late specialization'. However, based on the current data, the early identification of players worthy of performing within adult competition would be problematic given the late developments in certain fitness characteristics, such as aerobic capacity. Furthermore, the current data has highlighted the gulf remaining between players at the under-17 age and adult rugby league players (see Comfort et al., 2011; Gabbett, 2005). As such, the potential to prematurely de-select players from talent development programmes (Scholarship/Academy) and encourage early peaks in performance exists (Bailey et al., 2010). That under-17 players appear to be physiologically and physically inferior to their professional adult counterparts should be recognized by rugby league coaches.

6.5 Conclusion

Youth rugby league players were typically characterized as later maturers, which may have been anticipated in a physically biased 'collision' sport (Gabbett, 2005). Amongst rugby league players, the ability to generate force and power over 10 m and 30 m intervals is a valuable indicator of selection and will develop at a faster rate than absolute measures of speed that appear to be largely influenced by maturational status. These characteristics appear to be related to the specificity of rugby league performance and ultimately enable greater horizontal propulsion over shorter distances. As such, an evaluation of force and power generation and its relationship to tackling and ball carrying as well as unopposed linear running would be a worthwhile future direction. It should be noted that the current study is merely representative of the players included within the case study and may poorly reflect the population norms for the tested performance and growth parameters. However, longitudinal studies of this type provide a valuable indication of the time course and magnitude of

physical development and changes in performance of rugby league players over later adolescence. This information can be used to gain a greater understanding of player development patterns in youth rugby league. For example, large annual (2.3%) gains in lean body mass appears to characterize youth rugby league players and is much larger than previously demonstrated in other team sports such as soccer and field hockey (Vantinen et al., 2011; Huijgen et al., 2010). Lean body mass also appears to support the ability to generate force and power, which were amongst the most important variables for selection. The later gain in aerobic capacity (under-17) provides practitioners (for the first time) with a notion of when to expect changes of this type. The continual use of each of the field-based measurement techniques utilised in the current study would be beneficial to clubs wishing to monitor the changes in performance across age group progressions and guide the talent identification process. Future research should consider evaluating the efficacy of talent development programmes over similar time periods in order to further understand the appropriateness of various training practices in improving the characteristics of physical size and performance that have been revealed herein.

Chapter 7: A longitudinal analysis of match performance and its relationship to anthropometry and physical performance in selected and unselected youth rugby league players

7.1 Introduction

The requirements of competitive match play have been well documented in adult rugby league players (McLellan et al., 2011; 2010; Waldron, et al., 2011; Sykes et al., 2009). For example, Super League players that complete a full match, have been reported to cover approximately 7,000 m ($\sim 90 \text{ m}\cdot\text{min}^{-1}$), with 1,000 m ($\sim 15 \text{ m}\cdot\text{min}^{-1}$) covered at high intensity (i.e. $> 14 \text{ km}\cdot\text{h}^{-1}$) (Waldron et al., 2011a). In addition, the interchange rule in rugby league, permitting up to 10 interchanges during any stage of a Super League match, often results in some players performing two briefer ($\sim 20 \text{ min}$; Waldron et al., 2012) and more intense (~ 25 to $30 \text{ m}\cdot\text{min}^{-1}$ at high intensity) playing periods. High intensity running progressively declines between the first and second half (Sirotic et al., 2009; Sykes et al., 2011), which is different amongst interchanged players (Waldron et al., 2012). However, little is understood regarding the demands of the match environment of youth rugby league players, particularly across consecutive seasons. The same case can be made for technical proficiency during match play, which has been sparsely investigated in youth rugby league (Gabbett et al., 2008a). Currently, youth rugby league practitioners have only a modest concept of match demands on which to base training practices and no information of the expected progressions in match-related characteristics during maturation. Observing annual progression rates in match performance alongside factors such as physical growth may help to inform current developmental practices during maturational periods in rugby league players.

In addition to its role as an indicator of development, the description of match performance has relevance for the identification of young talented team sports players. For example, in soccer, match-related performance appears to underpin judgements of talent amongst elite coaches (Christensen, 2009; Vrljic & Mallet, 2008) which has also been defined as “someone

who *performs* better than his or her peers *during competition* and who has the potential to reach the elite level” (Elferink-Gemser et al., 2004, p. 1053, emphases added). However, whilst the limitations of identifying higher ability from performance measurements taken in a field or laboratory (closed) environment have been expressed (Lidor, 2009; Vaeyens et al., 2009; Falk et al., 2004), no research to date has measured performance from the match environment for such purposes. Furthermore, whilst some authors have related aerobic capacity to match running performance amongst youth soccer players (Castagna et al., 2009), the extent of the relationship between broader physical assessments and match performance is poorly understood, particularly in youth rugby league players. The existence of such a relationship may serve to validate the use of closed performance tests for identification purposes.

The aims of the present study were, firstly, to evaluate the technical, movement, HR and perceptual responses of youth rugby league players during the first and second halves of match play across a period of three seasons (under-15 to under-17). Such information is important for practitioners since there is currently no published profile of youth rugby league match play. After considering the match performance of youth players, differences between age groups and players being coach-selected or unselected at the conclusion of each season were evaluated over the study period. It was a final aim to identify the relationship between selected match performance characteristics and measurements of closed performance, anthropometry and maturity.

7.2 Methods

7.2.1 Participants

Table 7.1 shows the number of participants that were assessed during each year of the study as well as the sub-sample ($n = 12$) of retained players that trained and played matches in each year group. The description and selection of participants was as described in Chapter 6. Ethical approval was granted to conduct the study by the Faculty of Applied Health Sciences Ethics Committee (Appendix 1) and informed consent was obtained from the participants, parent/guardians, and the Rugby Football League (RFL) (Appendices 2 & 3). The players were monitored over a three season period (under-15 group to the under-17 group; February 2010 to June 2012) with the players' birth dates falling within the years of 1994 and 1995. Whilst the final age group under analysis is referred to herein as the under-17 group, players were contracted to the club as under-18 Academy players, resulting in an amalgamation with players one year older. The players were either coach selected or unselected at the conclusion of each season. All of the players typically took part in two to three training sessions per week, consisting of field-based aerobic training, gym-based resistance training, and small-sided rugby games.

Table 7.1. Sample sizes (n) of the selected (S) and unselected (Un) players at the end of each year group

Under-15 group		Under-16 group		Under-17 group		Three Year Cohort
S	Un	S	Un	S	Un	-
$n = 16$	$n = 5$	$n = 13$	$n = 8$	$n = 8$	$n = 6$	$n = 12$

7.2.2 Design

Each of the players included in Table 7.1 was assessed for variables of match-related performance (minimum of two and maximum of five performances), which included

measures of technical skill, heart rate, perceptual responses and movement demands. During the spring/summer competition period (beginning of March to the end of June), a total of 72 (distributed across six matches), 60 (distributed across six matches) and 68 (distributed across seven matches) performances were analyzed in the under-15 group, under-16 group and under-17 group, respectively. Mean match time was 64.1 ± 2.3 minutes in the under-15 group, 74.5 ± 3.3 minutes in the under-16 group and 85.2 ± 4.1 minutes in the under-17 group. Of the 19 matches analyzed, 17 were won and 2 were lost. Players were analyzed only during the time spent performing, which was different for all players. In rugby league, teams are permitted to interchange players at any given time point, often resulting in players from the forward group performing two separate bouts of play. An interchange allowance of 10 was permitted in the under-15 group and -16 age groups, which was decreased to 8 in the under 18 age group owing to changes in the laws of the game (RFL, 2011).

7.2.3 Procedure: Movement analysis

Movement analysis was performed using portable GPS devices (SPI-Pro; 5Hz, GPSports, Canberra, Australia) integrated with an in-built 6 g tri-axial accelerometer (100 Hz). Prior to the commencement of the research, the players underwent a familiarization period involving the GPS devices used during training sessions and subsequent pre-season (friendly) matches. The players were encouraged to continue with their normal match day preparations throughout the testing period.

All of the in-season matches took place between the times of approximately 11:00 and 15:00 either at the home ground of the rugby league club (England, North West) or at various

grounds situated throughout the North of England. For all matches throughout the testing period, a mean of 9 ± 1 (ranging between 6 – 12) satellites were determined as available for signal transmission using Team AMS V2.1 software (GPSports, Canberra, Australia), which is the same as previously reported as being optimal for assessing human movement (Jennings et al., 2010). The mean horizontal dilution of precision (HDOP) was 1.58 ± 0.43 and ranged from 0.87 to 2.01 for all recorded matches. A HDOP of 1 indicates an optimal geometrical positioning of orbiting satellites for accurate monitoring of position, whilst higher values (up to 50) may provide unreliable results (Witte & Wilson, 2005; Jennings et al., 2010). The mean temperature of all the matches was 9.3 ± 3.6 °C.

All GPS units (maximum of sixteen per match) were simultaneously activated at pitch side, approximately fifteen minutes prior to the ‘warm up’ period. Players were pre-fitted with an appropriately sized vest housing the portable GPS unit between the scapulae. A standard squad shirt was worn over the top of the vest. The GPS device (mass of 86 g, 0.8 x 0.4 x 0.2 cm) was fitted to the vest of the player upon entering the field for the warm up. A digital watch was synchronized with Greenwich Mean Time (GMT) and used to record the start and end of each half, as signalled by the referee. These times were later used to truncate the raw GPS data file. In addition, the time of interchanged players was recorded live and used to further truncate raw data. All data were downloaded to a computer using SPI Ezy V2.1 (GPSports, Canberra, Australia) and analyzed using Team AMS V2.1 software (GPSports, Canberra, Australia).

Twenty one different movement variables were considered for analysis within the current study, comprising: playing interval (min), total distance covered (m), relative distance

covered ($\text{m}\cdot\text{min}^{-1}$), and both total and relative distance within six discernable speed categories (zones 1 to 6). Individualisation of speed zones has been previously suggested by Abt and Lovell (2009) using the speed associated with certain physiological thresholds such as the second ventilatory threshold. The current study adopted a field-based approach, individualising speed categories to each player based upon annually updated recordings of mean sprinting speed over 30 m (zone 6)^a and running speed associated with the final stage of the multi-stage fitness test (maximal aerobic velocity; V_{max} = zone 5)^b. Zones 4, 3, 2 and 1 were calculated as; 75 - 100%, 50 - 75%, 25 - 50%, 0 - 25% of V_{max} , respectively. Distance in zones 4 and above were regarded, and hereafter referred to, as high-intensity (HIT). This category represents movement intensities within and above the highest quartile of maximal aerobic speed and is also within the margins of the speed associated with lactate threshold (high intensity demarcation; Jones & Doust, 2001) amongst adolescent soccer players (see McMillan et al., 2005). The mean V_{max} speed within each year group was $13.9 \pm 0.7 \text{ km}\cdot\text{h}^{-1}$ (under-15 group), $13.9 \pm 0.6 \text{ km}\cdot\text{h}^{-1}$ (under-16 group) and $14.3 \pm 0.7 \text{ km}\cdot\text{h}^{-1}$ (under-17 group). The mean sprinting zone (zone 6) was $21.1 \pm 1.2 \text{ km}\cdot\text{h}^{-1}$, $21.5 \pm 1.0 \text{ km}\cdot\text{h}^{-1}$, $22.2 \pm 0.9 \text{ km}\cdot\text{h}^{-1}$, within the under-15, -16 and -17 groups, respectively. Previous analyses have yielded ‘moderate’ to ‘good’ reliability (3% to 9% CV) using a similar demarcation of zones (Petersen et al., 2009), which is sufficient to tolerate threats to reliability. Further outcome variables included: frequency of sprints (n), mean sprint distance (m), sprints per minute ($\text{sprints}\cdot\text{min}^{-1}$), peak sprint distance (m) and peak sprint speed ($\text{km}\cdot\text{h}^{-1}$). In Chapter 3 of the current thesis, the coefficient of variation (CV%) between the current GPS units and calculated timing gate speed for over-ground sprinting was established at 9.8% (95% LoA = $2.05 \pm 3.62 \text{ km}\cdot\text{h}^{-1}$), 8.5% (95% LoA = $2.19 \pm 3.34 \text{ km}\cdot\text{h}^{-1}$) and 6.6% (95% LoA = $2.01 \pm 2.18 \text{ km}\cdot\text{h}^{-1}$) for 10, 20 and 30 m intervals, respectively. Data from the same analysis also

^a See Chapter 3 for Methods of sprint performance assessment using Global Positioning System devices

^b See Chapter 6 for multi-stage fitness test details

demonstrated test-retest reliability CV% ranging from 1.84 - 2.06% (95% LoA = -0.08 ± 1.75 m to -0.23 ± 1.42 m) and 1.92 - 2.06% (95% LoA = 0.05 ± 1.05 km·h⁻¹ to -0.09 ± 0.84 km·h⁻¹) for GPS measurements of distance and speed, respectively.

7.2.4 Procedure: Heart rate (HR) and ratings of perceived exertion (RPE)

A HR monitor (Polar Electro, Oy, Finland) was attached around the chest of the player, remaining in contact with the skin and secured using hyperfix tape. Heart rate was recorded at five second intervals using the above-mentioned GPS device. Peak heart rate (HR_{peak}) values were obtained prior to data collection, defined as the highest value reached during a 20 m shuttle running protocol to volitional exhaustion (Multi stage fitness test: Leger & Lambert, 1982). Heart rates (b·min⁻¹) were recorded during match time and were later calculated as a percentage of each player's pre-determined peak heart rate (%HR_{peak}). Summated heart rate was calculated based upon the method of Edwards (1993) presented below;

$$\begin{aligned} &(\text{Duration in zone 1} \times 1) + (\text{Duration in zone 2} \times 2) + (\text{Duration in zone 3} \times 3) \\ &+ (\text{Duration in zone 4} \times 4) + (\text{Duration in zone 5} \times 5) \end{aligned}$$

Where zone 1 = 50% to 60% of HR_{peak}, zone 2 = 60% to 70% HR_{peak}, zone 3 = 70% to 80% HR_{peak}, zone 4 = 80% to 90% HR_{peak}, and zone 5 = 90% to 100% HR_{peak} (Borresen & Lambert, 2008, p. 19).

Twenty minutes post-match, players were asked to provide a global ('session') RPE for the match using the 0 – 10 scale (Foster et al., 2001). This method uses an adapted 0 – 10 scale and multiplies given values by the duration of exercise time. Players were also habituated to

using the session RPE (sRPE) scale during the pre-season period and given explicit instruction regarding the interpretation of exertion in relation to the verbal anchors experienced through exercising. However, limited external instruction is also advocated with this measure since it represents a post-event global perception of exercise and should not be influenced by focussing purely on the more difficult periods of the exercise bout (Foster et al., 2001). Such methods appear to be reliable over various exercise intensities, showing no systematic change between repeated trials (Herman et al., 2006).

7.2.5 Procedure: Filming and performance analysis

For all matches, a camera (Canon MV 700i, 50 Hz, Japan) was fixed to a tripod (Velbon, DV7000, Japan) and positioned in a gantry at a height of approximately 15 m perpendicular to the half-way line. Prior to recording, the team coach marked the number of each player into a corresponding position on a pitch schematic, inclusive of substitutes. Players were later identified by the number on the back of their shirt, visual familiarization, field position or by default (in comparison to other players). Raw footage of each match was downloaded to a PC and imported to a manually operated behavioural recognition system (Dartfish TeamPro, 4.0.9.0, Switzerland). Post-match analysis of successful and unsuccessful carries and tackles were undertaken using the ‘tagging’ application (Table 7.2).

Table 7.2. Descriptions and acronyms for rugby league-specific performance indicators

Code	Performance Indicator
CaS	Carries successful
CaU	Carries unsuccessful
TaS	Tackles successful
TaU	Tackles unsuccessful

Note: see Appendix 4 for operational definitions.

All variables were expressed relative to the amount of playing time in order to normalize the data for each player (i.e. $\text{TaS} \cdot \text{min}^{-1}$ = successful tackles per playing minute). The intra-observer reliability of the selected match variables was assessed using the method of Cooper et al. (2007) and is presented in Table 7.3. A randomly selected 60-minute match from the study was coded for the above performance indicators on two different occasions, separated by two weeks. The frequency data from each trial were later separated into 40 equal chronological time segments (i.e. the first 1.5 min through to the final 1.5 min) and aligned for analysis. Each performance indicator was evaluated for systematic bias using a median-sign test to compare the data of trials 1 and 2. Random variation was evaluated based upon the proportion (%) of perfect agreement (PA) and agreement within a reference value of plus or minus 1 (± 1). These practical reference values represent the smallest possible error and were deemed appropriate given the experience of the analyst (six years in performance analysis) and familiarity with the sport and players involved. The differences between groups in the study were later considered in relation to the degree of random error shown in Table 7.3.

Table 7.3. Intra-observer reliability of selected performance indicators

Indicator	Median-Sign Test (<i>P</i>-value)	PA = 0 (%)	95% Confidence Interval (%)	PA ± 1 (%)	95% Confidence Interval (%)
CaS	1.000	91.9	78.9 to 100	100	100 to 100
CaU	0.500	94.5	83.8 to 100	100	100 to 100
TaS	1.000	100	100 to 100	100	100 to 100
TaU	1.000	100	100 to 100	100	100 to 100

Note: PA = perfect agreement; PA ± 1 = agreement within plus or minus 1. See table 7.2 for performance indicator abbreviations.

The intra-observer reliability tests showed no systematic bias between trials 1 and 2 and 100% perfect agreement for successful and unsuccessful tackles. 91.9% and 94.5% perfect agreement was determined for successful and unsuccessful carries which improved to 100% when the practical reference value was extended to plus or minus 1.

7.2.6 Statistical Analyses

The mean match performances of players that were either selected or unselected at the conclusion of each age group were compared using independent *t*-tests or Mann-Whitney-U tests, depending upon the distribution of the data set. A secondary analysis of the same data was performed using a one-way analysis of co-variance with PHV as a covariate (one-way ANCOVA). Data following a normal distribution were expressed as means and standard deviations (SD), whereas non-normal data were expressed as medians and inter-quartile ranges (IQR) throughout.

In a separate analysis, Annual data plots for mean match performance amongst players retained ($n = 12$) over the study period were evaluated using a series of one-way analyses of

variance with repeated measures (one-Way RM-ANOVA). Age group (under-15, -16 and -17) was adopted as the independent variable. Paired t -tests were used to identify specific differences between age groups. Where data did not meet the criteria for normal distribution (Shapiro-Wilk > 0.05), a Friedman test was applied, with follow-up Wilcoxon-Signed-Rank tests to identify pairwise differences between age groups.

Using paired t -tests, differences in %HR_{peak}, and $\text{m}\cdot\text{min}^{-1}$ within the six speed categories as well as HIT $\text{m}\cdot\text{min}^{-1}$ and total $\text{m}\cdot\text{min}^{-1}$ between the first and second half were assessed for players that completed a full match. Further comparisons of first and second half performances in which players completed 50% to 75% of the period (interchanged players) were carried out using paired t -tests. Such a period was selected since this represents the typical proportion of match time performed by an interchanged player (Waldron et al., 2012) and meets the criterion of previous methods in motion-analysis of team sport, whereby performances $>70\%$ of match time have been regarded as representative of whole matches (Aughey, 2010; Sykes et al., 2009). To reduce the effect of bout length, the players that performed for less than a full match but more than 70% were discarded from between-half analysis as were players who performed for less than 50% of any half. Over the three season period, mean first and second half playing periods of interchanged players ($n = 32$) was 24.4 ± 5.7 minutes and 21.3 ± 5.1 minutes, respectively with 26.4 ± 8.1 minutes recovery (i.e. not on the pitch).

Pearson's correlation coefficient (r) was used to assess the bivariate relationships between the match performance characteristics of: total $\text{m}\cdot\text{min}^{-1}$, HIT min^{-1} , RPE and %HR_{peak}, and measurements of closed performance, maturation and body size that were previously

identified in Chapter 6 (see Chapter 6, section 2 for full details of data collection). Where data were non-normally distributed, a Spearman's rank coefficient (R) was used. Tests were performed over each year of competition. The r value was interpreted according to arbitrary values suggested by Cohen (1992) where 0.1 = small, 0.3 = medium and 0.5 > = large. Significance was initially set a $P < 0.05$ for all statistical processes and later adjusted using the Benjamini-Hotchberg false discovery rate to control the type I error rate.

7.3 Results

7.3.2 Annual changes in match performance characteristics

Based upon the performances of 12 players who participated within each age group, the RM-ANOVAs showed overall age group effects on playing interval ($F_{(2,22)} = 4.842$, $P = 0.018$), with differences occurring between the under-15 group and under-17 group (50.9 ± 10.4 min c.f. 66.9 ± 18.8 min, respectively; $P = 0.029$) as well as the under-16 group and under-17 group (56.1 ± 11.9 min c.f. 66.9 ± 18.8 min, respectively; $P = 0.016$) (Table 7.4). There were further effects for total distance ($F_{(2,22)} = 6.910$, $P = 0.005$) and for distance covered within zone 1 ($F_{(2,22)} = 4.133$, $P = 0.009$), zone 2 ($F_{(2,22)} = 5.937$, $P = 0.030$), zone 3 ($F_{(2,22)} = 3.532$, $P = 0.046$), zone 4 ($F_{(2,22)} = 16.972$, $P < 0.001$), zone 5 ($F_{(2,22)} = 12.884$, $P < 0.001$) and zone 6 ($F_{(2,22)} = 5.840$, $P = 0.009$). For total distance covered, specific differences were found between the under-15 group and under-17 group (4179.3 ± 889.1 m c.f. 5878.8 ± 1564.3 m, respectively; $P = 0.011$) as well as the under-16 group and under-17 group (5058.9 ± 1041.7 m c.f. 5878.8 ± 1564.3 m, respectively; $P = 0.025$). Whilst differences were observed only between the under-15 group and under-16 group for distance in zone 4 ($P < 0.001$) and zone 5 ($P = 0.029$), more differences were found between the under-16 group and under-17 for zone 1 (558.4 ± 166.7 m c.f. 676.3 ± 237.7 m, respectively; $P = 0.013$), zone 2

(1769.1 \pm 471.9 m c.f. 2061.7 \pm 693.6 m, respectively; $P = 0.030$), zone 3 (963.5 \pm 257.7 m c.f. 1154.7 \pm 331.5 m, respectively; $P = 0.037$), zone 5 (700.5 \pm 197.4 m c.f. 879.4 \pm 260.1 m, respectively; $P = 0.014$) and zone 6 (192.8 \pm 99.3 m c.f. 103.1 \pm 45.3 m, respectively; $P = 0.007$) (Table 7.4).

Table 7.4. The mean differences (\pm SD) and percentage change (% Δ) between annual age groups (under-15 to under-17) in playing interval (min), total distance (m) and both total and relative ($\text{m}\cdot\text{min}^{-1}$) distance covered in six speed zones.

	Mean % Δ	U15-16 mean rate of change ($\text{n}\cdot\text{year}^{-1}$)	Mean % Δ	U16-U17 mean rate of change ($\text{n}\cdot\text{year}^{-1}$)
<i>Interval (min)</i>	10.1	5.1 \pm 18.0	19.4*	10.9 \pm 13.3
<i>Total distance (m)</i>	21.1	879.7 \pm 1619.1	16.2*	819.9 \pm 1093.1
<i>Total $\text{m}\cdot\text{min}^{-1}$</i>	11.1*	9.0 \pm 7.7	-1.9	-1.7 \pm 3.2
<i>Distance in Zone 1 (m)</i>	8.7	44.9 \pm 208.4	21.1*	117.9 \pm 137.6
<i>Distance in Zone 2 (m)</i>	16.0	244.4 \pm 739.1	16.5*	292.6 \pm 406.2
<i>Distance in Zone 3 (m)</i>	14.5	122.3 \pm 421.2	19.8*	191.2 \pm 278.8
<i>Distance in Zone 4 (m)</i>	33.9*	225.0 \pm 153.6	13.0	115.5 \pm 234.2
<i>Distance in Zone 5 (m)</i>	42.2*	207.9 \pm 286.7	25.5*	178.8 \pm 213.4
<i>Distance in Zone 6 (m)</i>	40.9	56.0 \pm 114.6	-46.6*	-89.8 \pm 93.3
<i>Z1 $\text{m}\cdot\text{min}^{-1}$</i>	0.1	0.01 \pm 1.1	0.3	0.0 \pm 0.6
<i>Z2 $\text{m}\cdot\text{min}^{-1}$</i>	8.9	2.5 \pm 5.9	-2.5	-0.8 \pm 2.6
<i>Z3 $\text{m}\cdot\text{min}^{-1}$</i>	4.5	0.7 \pm 3.9	-0.6	-0.1 \pm 2.9
<i>Z4 $\text{m}\cdot\text{min}^{-1}$</i>	33.7	4.6 \pm 7.3	-14.8	-2.7 \pm 7.6
<i>Z5 $\text{m}\cdot\text{min}^{-1}$</i>	35.2*	3.3 \pm 3.8	5.6	0.7 \pm 1.6
<i>Z6 $\text{m}\cdot\text{min}^{-1}$</i>	16.3	0.5 \pm 1.9	-50.6*	-1.7 \pm 1.7

Note: * = difference (< 0.05) during the age group transition in question. U15 = under-15 group; U16 = under-16 group; U17 = under-17 group.

There were overall age group effects on total $\text{m}\cdot\text{min}^{-1}$ ($F_{(2,22)} = 15.553$, $P < 0.001$) as well as for zone 5 $\text{m}\cdot\text{min}^{-1}$ ($F_{(2,22)} = 11.557$, $P = 0.007$) and zone 6 $\text{m}\cdot\text{min}^{-1}$ ($F_{(2,22)} = 6.920$, $P = 0.005$). For total $\text{m}\cdot\text{min}^{-1}$, *post-hoc* pairwise comparisons highlighted differences between the under-15 and both the under-16 group (81.5 \pm 5.0 $\text{m}\cdot\text{min}^{-1}$ c.f. 90.5 \pm 4.8 $\text{m}\cdot\text{min}^{-1}$, respectively; $P = 0.002$) and under-17 group (81.5 \pm 5.0 $\text{m}\cdot\text{min}^{-1}$ c.f. 88.7 \pm 4.1 $\text{m}\cdot\text{min}^{-1}$, respectively; $P = 0.002$). Similarly, zone 5 $\text{m}\cdot\text{min}^{-1}$ was higher in the under-16 group (12.7 \pm

2.5 m·min⁻¹, $P = 0.012$) and under-17 group (13.4 ± 2.4 m·min⁻¹, $P = 0.002$) compared to the under-15 group (9.37 ± 2.3 m·min⁻¹). For zone 6 m·min⁻¹, specific differences occurred between the under-16 group and under-17 group (3.5 ± 1.4 m·min⁻¹ c.f. 1.7 ± 0.9 m·min⁻¹, respectively; $P = 0.005$) and the under-15 group and under-17 group (2.9 ± 1.0 m·min⁻¹ c.f. 1.7 ± 0.9 m·min⁻¹, respectively; $P = 0.007$) (Table 7.4).

Table 7.5. The mean differences (\pm SD) and percentage change (% Δ) between annual age groups (under-15 to under-17) in total (m) and relative high intensity distance covered (HIT·min⁻¹), total (n) and relative (n·min⁻¹) sprint frequency, mean sprint distance (m) and peak sprint speed (km·h⁻¹) and distance (m).

	Mean % Δ	U15-U16 mean rate of change (n·year ⁻¹)	Mean % Δ	U16-U17 mean rate of change (n·year ⁻¹)
Distance HIT (m)	37.8*	489.0 \pm 419.9	11.5	204.5 \pm 408.0
HIT·min⁻¹	23.8*	6.2 \pm 4.8	-4.2	-1.4 \pm 3.2
Sprints (n)	27.7	3.7 \pm 10.1	-38.8*	-6.7 \pm 6.4
Sprints·min⁻¹	13.7	0.03 \pm 0.2	-43.9*	-0.1 \pm 0.1
Mean sprint distance (m)	3.7	0.4 \pm 4.4	-12.2	-1.4 \pm 4.5
Peak sprint distance (m)	11.7	4.3 \pm 13.5	-26.7*	-11.0 \pm 15.3
Peak speed (km·h⁻¹)	4.7	1.3 \pm 2.2	-1.5	-0.4 \pm 1.7

Note: * = difference (< 0.05) during the age group transition in question. U15 = under-15 group; U16 = under-16 group; U17 = under-17 group. HIT = high intensity.

As presented in Table 7.5, the RM-ANOVAs revealed overall age group effects on Distance HIT ($F_{(2,22)} = 17.079$, $P < 0.001$) and HIT·min⁻¹ ($F_{(2,22)} = 11.109$, $P < 0.001$). Follow-up comparisons identified significant differences in HIT distance between the under-15 group and under-16 group (1292.5 ± 297.2 m c.f. 1781.5 ± 379.3 m, respectively; $P = 0.002$) and the under-15 group and under-17 group (1292.5 ± 297.2 m c.f. 1986.2 ± 468.2 m, respectively; $P = 0.002$), which were mirrored by differences in HIT·min⁻¹ between the under-15 group and under-16 group (26.0 ± 4.7 m·min⁻¹ c.f. 32.2 ± 4.7 m·min⁻¹, respectively; $P = 0.001$) and the under-15 group and under-17 group (26.0 ± 4.7 m·min⁻¹ c.f. 30.9 ± 5.4 m, respectively; $P = 0.017$). An age group effect was also observed for sprint number ($F_{(2,22)} =$

4.350, $P = 0.026$), sprints·min⁻¹ ($F_{(2,22)} = 6.324$, $P = 0.007$) and peak sprint distance ($F_{(2,22)} = 3.847$, $P = 0.037$). Between the under-16 group and under-17 group, specific differences were identified for sprint frequency (17.2 ± 8.3 c.f. 10.5 ± 4.5 , respectively; $P = 0.004$) and peak sprint distance (41.1 ± 9.8 m c.f. 30.7 ± 10.7 m, respectively; $P = 0.030$). Similarly, sprints·min⁻¹ were higher in the under-16 group compared to the under-17 group (0.27 ± 0.07 sprints·min⁻¹ c.f. 0.17 ± 0.08 sprints·min⁻¹, respectively; $P = 0.030$).

Table 7.6. The mean differences (\pm SD) and percentage change (% Δ) between annual age groups (under-15 to under-17) in %HR_{peak}, summated HR and perceptual responses.

	Mean % Δ	U15-U16 mean rate of change (n·year ⁻¹)	Mean % Δ	U16-U17 mean rate of change (n·year ⁻¹)
%HR_{peak}	4.1*	3.4 \pm 3.2	-0.5	-0.4 \pm 2.4
Summated HR (AU)	12.4	22.5 \pm 80.2	19.1	38.8 \pm 52.7
RPE	11.6	0.8 \pm 1.2	-9.6	-0.7 \pm 0.9
sRPE (AU)	20.1*	70.6 \pm 171.3	9.6*	40.5 \pm 110.6

Note: * = difference (< 0.05) during the age group transition in question. U15 = under-15 group; U16 = under-16 group; U17 = under-17 group. RPE = rating of perceived exertion; sRPE = session RPE; AI = Arbitrary units.

Age group was seen to effect %HR_{peak} ($F_{(2,22)} = 7.008$, $P = 0.004$), summated-HR ($F_{(2,22)} = 4.305$, $P = 0.026$) and RPE ($F_{(2,22)} = 4.086$, $P = 0.031$). For %HR_{peak}, *post-hoc* comparisons isolated significant differences between the under-15 group and both the under-16 group ($79.2 \pm 4.8\%$ c.f. $82.4 \pm 3.2\%$, respectively; $P = 0.007$) and under-17 group ($79.2 \pm 4.8\%$ c.f. $82.9 \pm 3.4\%$, respectively; $P = 0.026$). Summated-HR differed between the under-16 group and under-17 group (203.4 ± 52.9 c.f. 242.3 ± 52.5 , respectively; $P = 0.027$) and the under-15 group and under-17 group (180.9 ± 52.6 c.f. 242.3 ± 52.5 , respectively; $P = 0.026$). Age group also impacted upon RPE ($F_{(2,22)} = 4.086$, $P = 0.031$), with specific differences evident between the under-15 and under-16 groups (6.8 ± 0.8 c.f. 7.5 ± 0.8 , respectively $P = 0.049$)

and the under-16 and under-17 groups (7.5 ± 0.8 c.f. 6.8 ± 0.7 , respectively; $P = 0.021$) (Table 7.6).

Friedman ANOVAs demonstrated an effect of age group on successful carries ($X^2 = 6.864$, $P = 0.032$), unsuccessful carries ($X^2 = 13.190$, $P = 0.001$), unsuccessful tackles ($X^2 = 15.224$, $P < 0.001$), unsuccessful carries·min⁻¹ ($X^2 = 18.167$, $P < 0.001$) and unsuccessful tackles·min⁻¹ ($X^2 = 12.500$, $P < 0.001$). Wilcoxon-Signed-Rank follow-up tests showed no specific differences ($P > 0.05$) between the under-15 and under-16 groups, but there were significant changes between the under-16 and under-17 groups for successful carries (Median = 7; IQR = 3 to 8 c.f. Median = 10; IQR = 7 to 14, respectively; $P = 0.021$), unsuccessful carries (Median = 1; IQR = 0 to 2 c.f. Median = 4; IQR = 2 to 7, respectively; $P = 0.004$), unsuccessful tackles (Median = 2; IQR = 1 to 4 c.f. Median = 6; IQR = 4 to 8, respectively; $P = 0.018$) and unsuccessful carries·min⁻¹ (Median = 0.020; IQR = 0.002 to 0.038 c.f. Median = 0.089; IQR = 0.059 to 0.094, respectively; $P = 0.002$) (Table 7.7).

Table 7.7. The mean differences (\pm SD) and percentage change (% Δ) between annual age groups (under-15 to under-17) in selected technical actions.

	Mean % Δ	U15-U16 mean rate of change (n·year ⁻¹)	Mean % Δ	U16-U17 mean rate of change (n·year ⁻¹)
<i>CaS</i>	5.9	0.37 \pm 3.06	56.6*	3.71 \pm 4.63
<i>CaU</i>	49.9	0.37 \pm 1.04	287.3*	3.15 \pm 2.25
<i>TaS</i>	1.0	0.11 \pm 5.63	4.8	0.53 \pm 4.79
<i>TaU</i>	32.7	0.60 \pm 2.33	127.2*	3.08 \pm 2.86
<i>CaS·min⁻¹</i>	-15.7	-0.02 \pm 0.03	49.6	0.05 \pm 0.09
<i>CaU·min⁻¹</i>	29.9	0.00 \pm 0.02	127.2*	0.43 \pm 0.27
<i>TaS·min⁻¹</i>	-26.9	-0.07 \pm 0.17	-1.8	0.00 \pm 0.08
<i>TaU·min⁻¹</i>	-15.9	-0.01 \pm 0.06	121.9	0.05 \pm 0.05

Note: * = difference (< 0.05) during the age group transition in question. U15 = under-15 group; U16 = under-16 group; U17 = under-17 group.

7.3.1 Comparison of selected and unselected players by age group

Independent *t*-tests showed no differences ($P > 0.05$) between the selected and unselected players among the under-15 or the under-17 age groups for any of the movement or physiological variables measured during match time. In the under-16 group, the selected players (57.1 ± 11.9 min) had more available time than the unselected (44.1 ± 12.3 min) players ($t_{(21)} = 2.580$, $P = 0.017$). In turn, selected players covered more total distance (5181.0 ± 1063.5 m c.f. 3942.6 ± 1108.6 m, respectively; $P = 0.012$) than unselected players as well as in zone 1 (572.4 ± 163.3 m c.f. 434.3 ± 135.0 m, respectively; $P = 0.039$), zone 3 (572.4 ± 163.3 m c.f. 434.3 ± 135.0 m, respectively; $P = 0.039$) and zone 4 (913.4 ± 188.8 m c.f. 686.5 ± 205.2 m, respectively; $P = 0.012$). Other time-related variables such as summated-HR (213.6 ± 55.4 c.f. 156.9 ± 74.0 , respectively; $P = 0.049$), HIT distance (1808.8 ± 369.3 m c.f. 1380.5 ± 367.7 m, respectively; $P = 0.011$) and sRPE (433.2 ± 93.2 c.f. 313.4 ± 81.2 , respectively; $P = 0.004$), were higher amongst selected players compared to unselected players (Tables 7.8, 7.9 & 7.10). When age at peak height velocity (PHV) was introduced as a covariate, only distance in zone 3 and summated-HR remained higher ($P < 0.05$) in the selected players of the under-16 age group. However, the ANCOVAs (using PHV as the covariate), revealed higher values ($P < 0.05$) amongst the unselected players for total and relative distance in zone 4, 5 and HIT.

The results of the Mann-Whitney-U tests showed that selected players performed more successful carries (Median = 6; IQR = 5 to 8 c.f. Median = 2; IQR = 1 to 3, $P < 0.001$) and successful carries \cdot min⁻¹ (Median = 0.127; IQR = 0.093 to 0.168 c.f. Median = 0.040; IQR = 0.0265 to 0.0845, $P < 0.001$) of the ball compared to unselected players in the under-15 group.

No other differences ($P > 0.05$) between selected and unselected players in technical match actions were apparent for any other age group (Table 7.11).

Table 7.8. Comparison of selected and unselected players by age group (under-15 to under-17) for playing interval (min), total distance (m) and both total and relative ($\text{m}\cdot\text{min}^{-1}$) distance covered in six speed zones.

	Under-15 group		Under-16 group		Under-17 group	
	Selected ($n = 18$)	Unselected ($n = 6$)	Selected ($n = 12$)	Unselected ($n = 11$)	Selected ($n = 9$)	Unselected ($n = 6$)
Interval (min)	49.8 \pm 10.8	53.8 \pm 12.1	57.2* \pm 12.0	44.1 \pm 12.3	73.0 \pm 14.7	55.4 \pm 23.0
Total distance (m)	4112.9 \pm 888.6	4478.8 \pm 898.2	5181.0* \pm 1063.5	3942.6 \pm 1108.6	6392.4 \pm 1238.7	4962.0 \pm 1958.9
Total $\text{m}\cdot\text{min}^{-1}$	81.2 \pm 5.7	84.4 \pm 5.8	90.8 \pm 5.0	88.7 \pm 4.5	88.0 \pm 3.8	90.9 \pm 3.4
Distance in Zone 1 (m)	492.2 \pm 122.8	528.2 \pm 162.6	572.4* \pm 163.3	434.3 \pm 135.0	748.0 \pm 218.0	550.3 \pm 250.7
Distance in Zone 2 (m)	1469.2 \pm 443.8	1495.6 \pm 638.7	1788.2 \pm 485.5	1369.1 \pm 526.3	2262.1 \pm 584.6	1666.1 \pm 828.4
Distance in Zone 3 (m)	839.6 \pm 252.7	915.4 \pm 295.0	1022.0*† \pm 256.5	759.8 \pm 229.1	1267.3 \pm 297.2	995.9 \pm 329.4
Distance in Zone 4 (m)	682.1 \pm 144.3	820.8 \pm 259.3	913.4* \pm 188.8	686.5† \pm 205.2	1092.4 \pm 269.0	854.6 \pm 233.0
Distance in Zone 5 (m)	493.8 \pm 191.4	600.3 \pm 318.7	711.0 \pm 195.6	581.8† \pm 212.2	925.3 \pm 198.0	803.4 \pm 383.4
Distance in Zone 6 (m)	131.3 \pm 25.0	121.2 \pm 48.6	184.4 \pm 104.4	112.2 \pm 64.7	97.8 \pm 52.3	91.5 \pm 39.3
Z1 $\text{m}\cdot\text{min}^{-1}$	9.6 \pm 0.9	9.6 \pm 1.3	9.9 \pm 1.2	9.9 \pm 1.2	10.1 \pm 1.5	9.7 \pm 0.9
Z2 $\text{m}\cdot\text{min}^{-1}$	27.9 \pm 4.0	27.1 \pm 6.1	30.9 \pm 3.1	30.4 \pm 4.9	30.8 \pm 3.2	29.2 \pm 3.7
Z3 $\text{m}\cdot\text{min}^{-1}$	16.8 \pm 2.6	17.0 \pm 2.8	18.1 \pm 3.6	17.1 \pm 3.7	17.4 \pm 2.6	18.5 \pm 3.3
Z4 $\text{m}\cdot\text{min}^{-1}$	14.4 \pm 3.7	16.7 \pm 7.7	18.5 \pm 7.8	17.8† \pm 4.6	15.4 \pm 4.4	16.5 \pm 3.5
Z5 $\text{m}\cdot\text{min}^{-1}$	9.6 \pm 3.0	11.8 \pm 6.2	12.6 \pm 2.6	13.2† \pm 3.2	12.8 \pm 1.7	14.5 \pm 2.9
Z6 $\text{m}\cdot\text{min}^{-1}$	2.8 \pm 0.9	2.2 \pm 0.6	3.2 \pm 1.5	2.6 \pm 1.3	1.4 \pm 0.8	1.8 \pm 0.9

Note: * = Larger (< 0.05) than comparative age group. † = Larger (< 0.05) than comparative age group under statistical control for maturational age. Adjusted means not presented.

Table 7.9. Comparison of selected and unselected players by age group (under-15 to under-17) for total (m) and relative high intensity distance covered ($\text{HIT} \cdot \text{min}^{-1}$), total (n) and relative ($\text{n} \cdot \text{min}^{-1}$) sprint frequency, mean sprint distance (m) and peak sprint speed ($\text{km} \cdot \text{h}^{-1}$) and distance (m).

	Under-15 group		Under-16 group		Under-17 group	
	Selected (n = 18)	Unselected (n = 6)	Selected (n = 12)	Unselected (n = 11)	Selected (n = 9)	Unselected (n = 6)
Distance HIT (m)	1307.2 \pm 327.9	1542.3 \pm 555.7	1808.8* \pm 369.3	1380.5† \pm 367.7	2115.5 \pm 373.5	1749.5 \pm 610.0
HIT·min⁻¹	26.8 \pm 6.5	30.7 \pm 13.2	32.2 \pm 4.7	31.7† \pm 5.6	29.8 \pm 5.4	33.1 \pm 4.2
Sprints (n)	13.2 \pm 2.6	12.4 \pm 5.3	17.0 \pm 8.5	10.9 \pm 5.9	9.6 \pm 3.9	10.3 \pm 5.2
Sprints·min⁻¹	0.3 \pm 0.1	0.2 \pm 0.1	0.3 \pm 0.1	0.2 \pm 0.1	0.1 \pm 0.1	0.2 \pm 0.1
Mean sprint distance (m)	10.5 \pm 3.2	9.9 \pm 2.6	10.8 \pm 3.0	10.1 \pm 4.8	12.6 \pm 6.8	8.5 \pm 4.1
Peak sprint distance (m)	35.9 \pm 7.8	36.9 \pm 9.3	38.4 \pm 8.6	30.8 \pm 15.8	31.2 \pm 11.7	24.8 \pm 9.3
Peak speed (km·h⁻¹)	27.0 \pm 1.1	27.2 \pm 1.5	28.2 \pm 1.6	27.4 \pm 3.4	28.0 \pm 2.0	27.4 \pm 1.5

Note: * = Larger (< 0.05) than comparative age group. † = Larger (< 0.05) than comparative age group under statistical control for maturational age. Adjusted means not presented.

Table 7.10. Comparison of selected and unselected players by age group (under-15 to under-17) for %HR_{peak}, summated HR and perceptual responses during match time.

	Under-15 group		Under-16 group		Under-17 group	
	Selected (n = 18)	Unselected (n = 6)	Selected (n = 12)	Unselected (n = 11)	Selected (n = 9)	Unselected (n = 6)
%HR_{peak}	78.8 \pm 4.8	79.7 \pm 3.7	83.0 \pm 3.0	82.4 \pm 5.0	82.1 \pm 2.0	83.2 \pm 3.3
Summated HR (AU)	178.0 \pm 47.4	194.8 \pm 51.6	213.6*† \pm 55.4	156.9 \pm 74.0	266.2 \pm 38.3	202.8 \pm 64.6
RPE	6.9 \pm 0.7	6.7 \pm 0.8	7.6 \pm 0.5	7.2 \pm 0.9	6.8 \pm 0.9	6.3 \pm 0.7
sRPE (AU)	353.8 \pm 98.7	358.8 \pm 99.7	433.2* \pm 93.2	313.4 \pm 81.2	498.9 \pm 117.3	353.5 \pm 165.8

Note: * = Larger (< 0.05) than comparative age group. † = Larger (< 0.05) than comparative age group under statistical control for maturational age. Adjusted means not presented.

Table 7.11. Comparisons between selected and unselected players by age group (under-15 to under-17) for selected technical actions

	Under-15 group		Under-16 group		Under-17 group	
	Selected (<i>n</i> = 16)	Unselected (<i>n</i> = 5)	Selected (<i>n</i> = 14)	Unselected (<i>n</i> = 7)	Selected (<i>n</i> = 9)	Unselected (<i>n</i> = 6)
<i>CaS</i>	6*	2	7	7	9	5
<i>CaU</i>	1	1	1	1	3	1
<i>TaS</i>	11	10	12	13	13	8
<i>TaU</i>	2	1	2	2	5	1
<i>CaS·min⁻¹</i>	0.13*	0.04	0.10	0.13	0.17	0.13
<i>CaU·min⁻¹</i>	0.01	0.01	0.02	0.01	0.30	0.03
<i>TaS·min⁻¹</i>	0.23	0.16	0.21	0.24	0.16	0.33
<i>TaU·min⁻¹</i>	0.02	0.02	0.04	0.04	0.08	0.07

Note: * = Larger ($P < 0.05$) than comparative age group. See Methods section for abbreviations. Confidence intervals were excluded for clarity.

7.3.3 Analysis of first to second half performances

During the under-15 age group, full-match players experienced decrements from the first to second half in zone 3 $\text{m}\cdot\text{min}^{-1}$ ($19.0 \pm 4.8 \text{ m}\cdot\text{min}^{-1}$ c.f. $16.2 \pm 4.1 \text{ m}\cdot\text{min}^{-1}$, respectively; $P = 0.021$), zone 4 $\text{m}\cdot\text{min}^{-1}$ ($14.9 \pm 4.1 \text{ m}\cdot\text{min}^{-1}$ c.f. $12.6 \pm 4.0 \text{ m}\cdot\text{min}^{-1}$, respectively; $P = 0.031$), zone 6 $\text{m}\cdot\text{min}^{-1}$ ($3.4 \pm 1.5 \text{ m}\cdot\text{min}^{-1}$ c.f. $2.4 \pm 1.3 \text{ m}\cdot\text{min}^{-1}$, respectively; $P = 0.007$), HIT $\text{m}\cdot\text{min}^{-1}$ ($29.3 \pm 8.2 \text{ m}\cdot\text{min}^{-1}$ c.f. $23.9 \pm 8.1 \text{ m}\cdot\text{min}^{-1}$, respectively; $P = 0.017$) and total $\text{m}\cdot\text{min}^{-1}$ ($89.7 \pm 5.6 \text{ m}\cdot\text{min}^{-1}$ c.f. $80.3 \pm 9.1 \text{ m}\cdot\text{min}^{-1}$, respectively; $P < 0.001$) (Figures 7.1 & 7.3). Interchanged players did not show any performance change ($P > 0.05$) between halves of the match in the under-15 group. In the under-16 group, both full-match and interchanged players experienced no change ($P > 0.05$) in any performance measure between halves (Figure 7.1, 7.2 & 7.3). However, in a similar fashion to the under-15 group, the under-17 group full-match players showed first to second half changes in zone 3 $\text{m}\cdot\text{min}^{-1}$ ($18.6 \pm 3.1 \text{ m}\cdot\text{min}^{-1}$ c.f. $14.5 \pm 4.5 \text{ m}\cdot\text{min}^{-1}$, respectively; $P < 0.001$), zone 4 $\text{m}\cdot\text{min}^{-1}$ ($14.5 \pm 4.1 \text{ m}\cdot\text{min}^{-1}$ c.f. $11.9 \pm 4.0 \text{ m}\cdot\text{min}^{-1}$, respectively; $P = 0.002$), HIT $\text{m}\cdot\text{min}^{-1}$ ($29.3 \pm 5.2 \text{ m}\cdot\text{min}^{-1}$ c.f. $24.9 \pm 6.1 \text{ m}\cdot\text{min}^{-1}$, respectively; $P = 0.002$) and total $\text{m}\cdot\text{min}^{-1}$ ($89.4 \pm 5.8 \text{ m}\cdot\text{min}^{-1}$ c.f. $82.7 \pm 4.8 \text{ m}\cdot\text{min}^{-1}$, respectively; $P < 0.001$). Interchanged players in the under-17 group also declined in total $\text{m}\cdot\text{min}^{-1}$ ($93.5 \pm 5.3 \text{ m}\cdot\text{min}^{-1}$ c.f. $88.1 \pm 5.7 \text{ m}\cdot\text{min}^{-1}$, respectively; $P = 0.024$) (Figure 7.3). No changes in $\%\text{HR}_{\text{peak}}$ were apparent between the first and second half ($P > 0.05$) periods for any players during any age group. Similarly, there were no differences ($P > 0.05$) in ball carries or tackles between the first and second half periods for any of the players (Table 7.12).

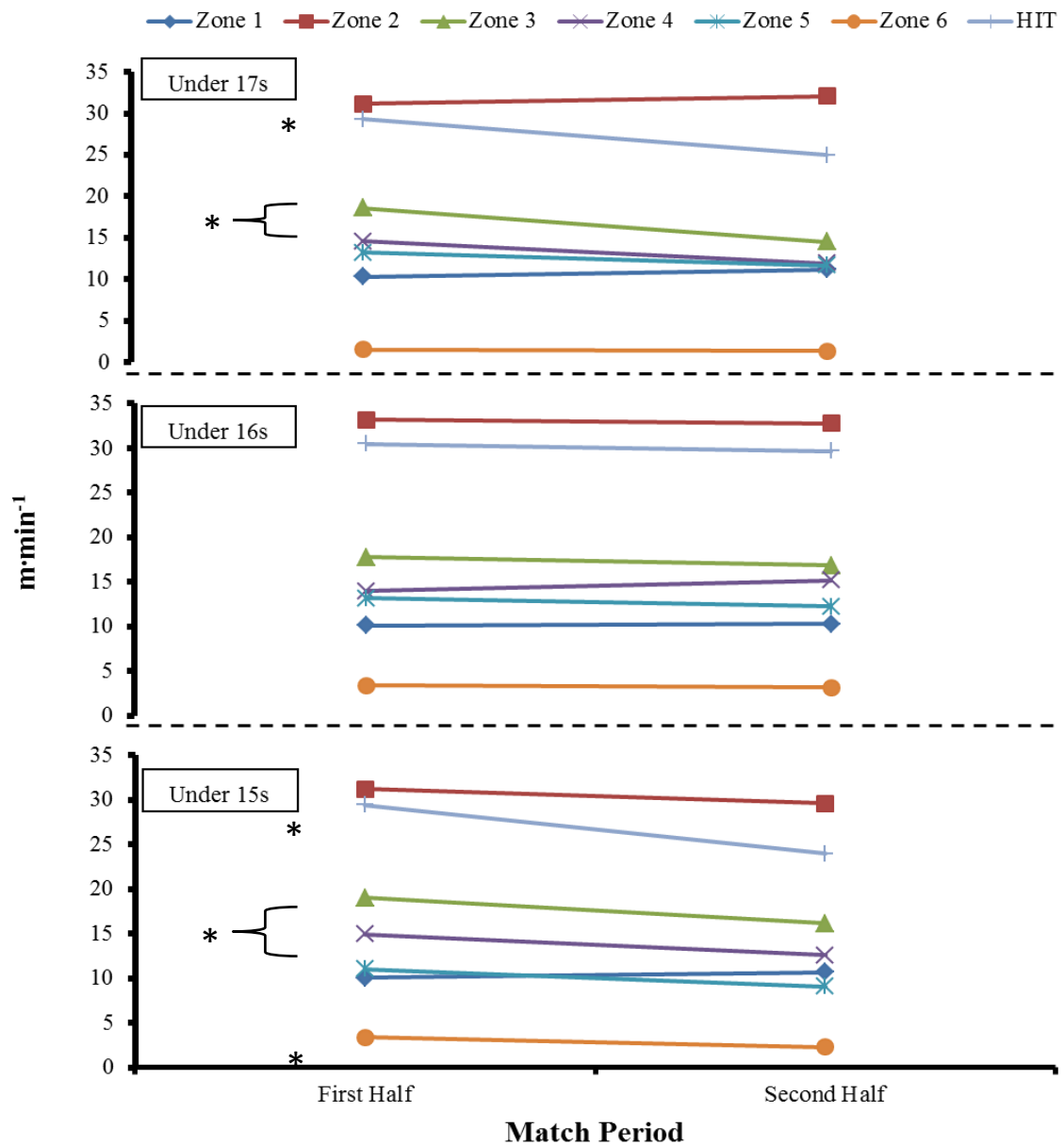


Figure 7.1. First to second half changes in the metres covered per minute ($\text{m} \cdot \text{min}^{-1}$) of full-match players (under-15, -16 and -17 groups) within six speed zones and high intensity (HIT). * = different ($P < 0.05$) to the second half.

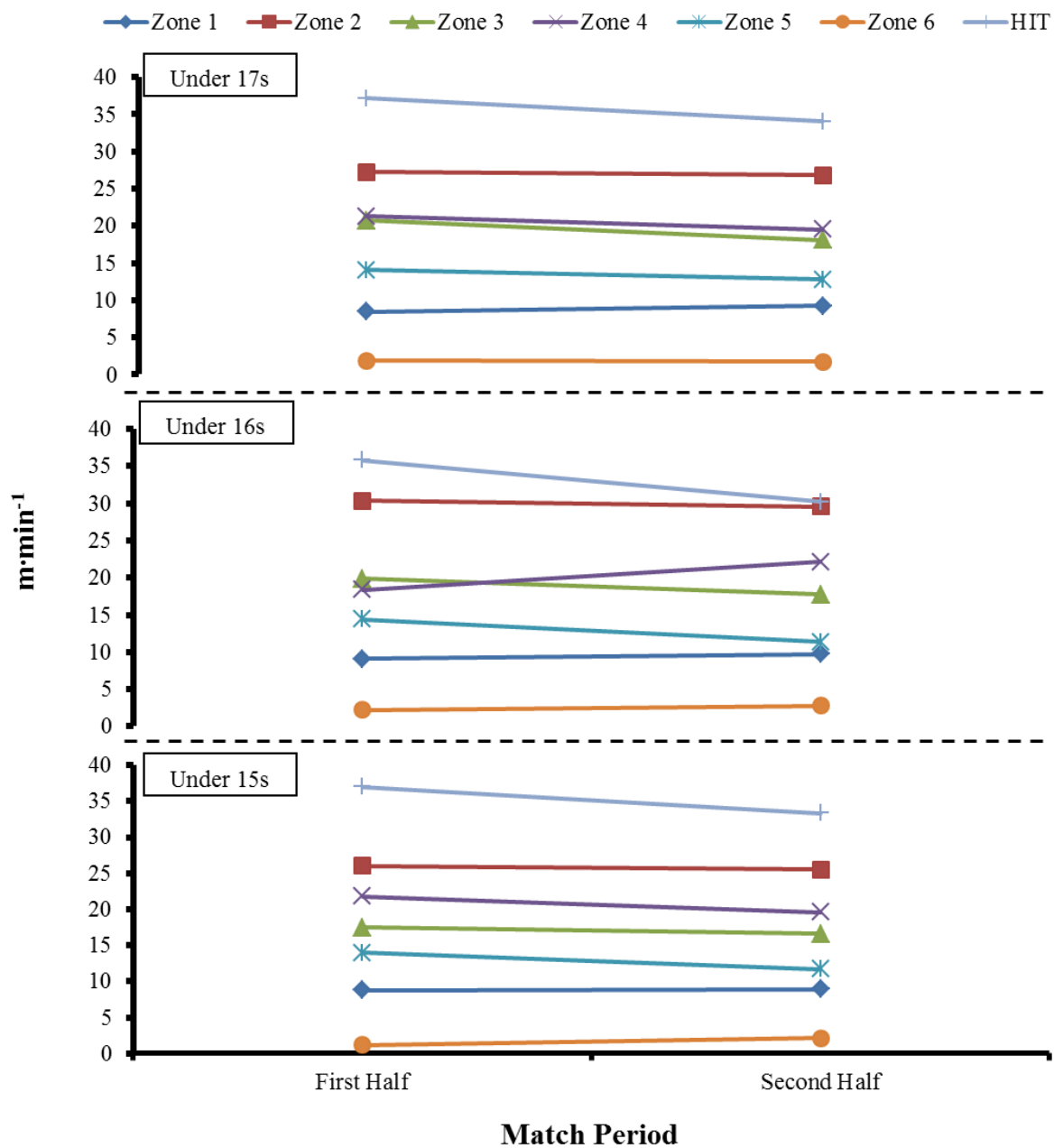


Figure 7.2. First to second half changes in the metres covered per minute ($\text{m} \cdot \text{min}^{-1}$) of interchanged match players (under-15, -16 and -17 groups) within six speed zones and high intensity (HIT).

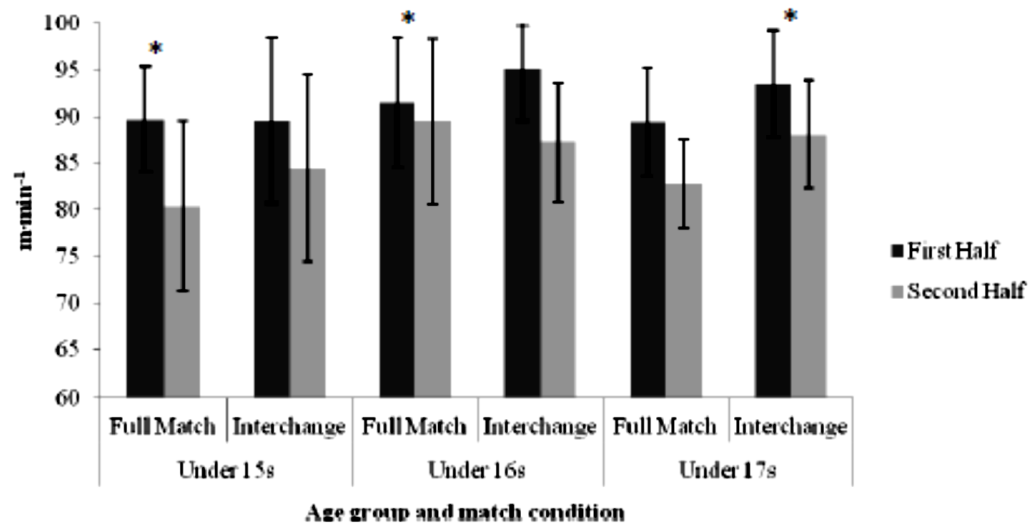


Figure 7.3. First to second half changes in the total metres covered per minute (min^{-1}) of full-match and interchanged players (under-15, -16 and -17 groups) * = different ($P < 0.05$) to the second half for that comparison.

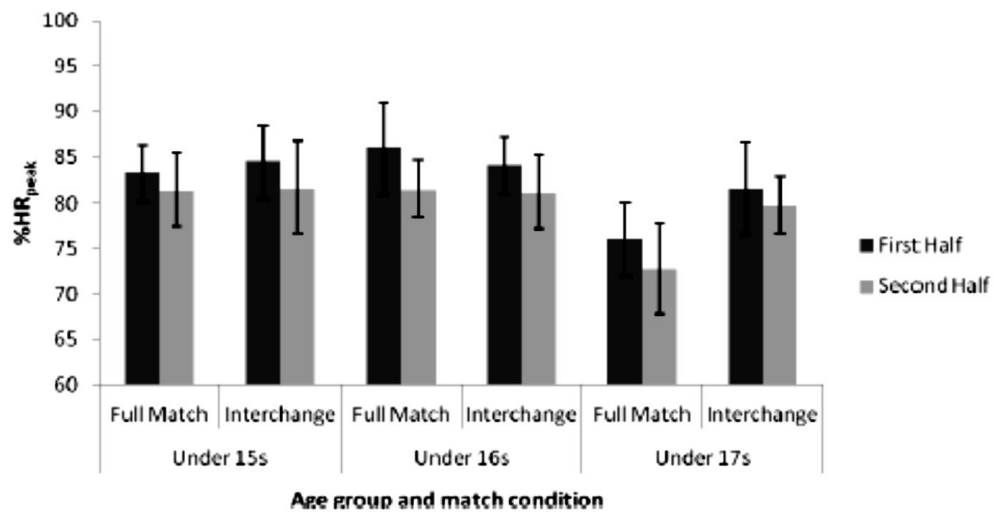


Figure 7.4. First to second half changes in % HR_{peak} of full-match and interchanged players (under-15, -16 and -17 groups).

Table 7.12. First to second half changes in successful or unsuccessful carries and tackles per minute of match time amongst full-match and interchanged players (under-15, -16 and -17 groups).

	Under-15 group				Under-16 group				Under-17 group			
	Whole match (<i>n</i> = 28)		Interchange (<i>n</i> = 12)		Whole match (<i>n</i> = 20)		Interchange (<i>n</i> = 8)		Whole match (<i>n</i> = 37)		Interchange (<i>n</i> = 13)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
<i>CaS</i>·<i>min</i>⁻¹	0.11	0.11	0.07	0.10	0.11	0.11	0.17	0.13	0.10	0.16	0.33	0.30
<i>CaU</i>·<i>min</i>⁻¹	0.03	0.03	0.05	0.06	0.03	0.03	0.04	0.03	0.05	0.02	0.08	0.12
<i>TaS</i>·<i>min</i>⁻¹	0.13	0.17	0.20	0.24	0.17	0.17	0.29	0.33	0.18	0.19	0.40	0.49
<i>TaU</i>·<i>min</i>⁻¹	0.03	0.00	0.05	0.05	0.03	0.03	0.04	0.07	0.03	0.02	0.08	0.06

7.3.4 Relationships between physical performance, growth and match performance

The relationships between age at peak height velocity (PHV) and match performance were not significant across all age groups ($P > 0.05$). Similarly, anthropometric variables such as body mass, lean body mass and stature were all unrelated to match running performance or HR and perceptual responses to the match, across all age groups ($P > 0.05$). In the under-15 and under-16 age groups, 20 m sprint time was positively (slower sprint time) correlated with HIT $\text{m} \cdot \text{min}^{-1}$ ($r = 0.44$, $P = 0.046$ & $r = 0.51$, respectively; $P = 0.022$), whereas $\dot{V}\text{O}_{2\text{max}}$ showed either an inverse or no relationship ($r = -0.460$, $P = 0.036$ & $r = -0.330$, $P = 0.156$, respectively) with HIT $\text{m} \cdot \text{min}^{-1}$. However, in the under-17 group, the relationship was reversed, whereby 20 m sprint time was unrelated to HIT $\text{m} \cdot \text{min}^{-1}$ ($r = -0.07$, $P = 0.798$) but $\dot{V}\text{O}_{2\text{max}}$ was positively correlated with HIT $\text{m} \cdot \text{min}^{-1}$ ($r = 0.51$, $P = 0.044$) (Figures 7.5 & 7.6).

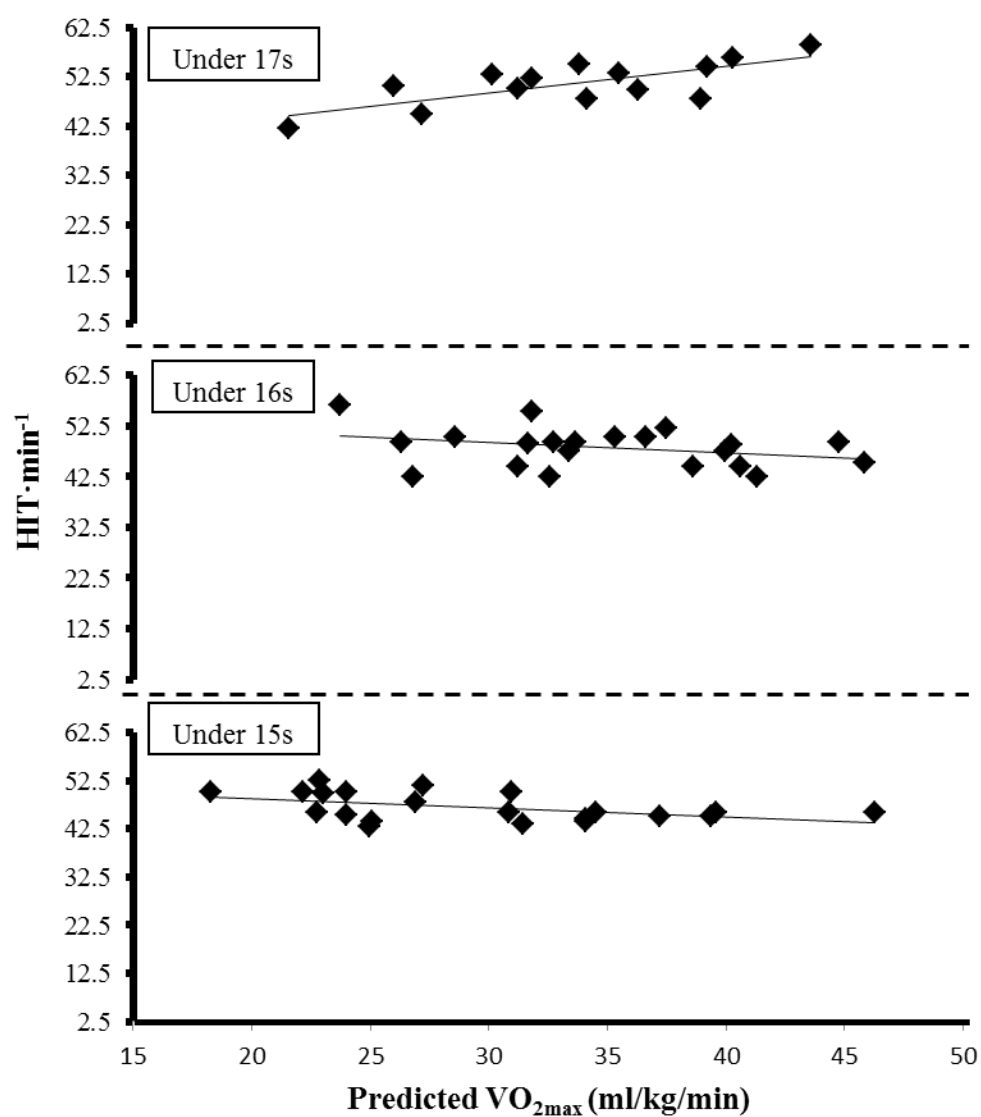


Figure 7.5. The relationship between high intensity running per minute of match time ($\text{HIT} \cdot \text{min}^{-1}$) and predicted $\dot{V}O_{2\max}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) for under-15, -16 and -17 players.

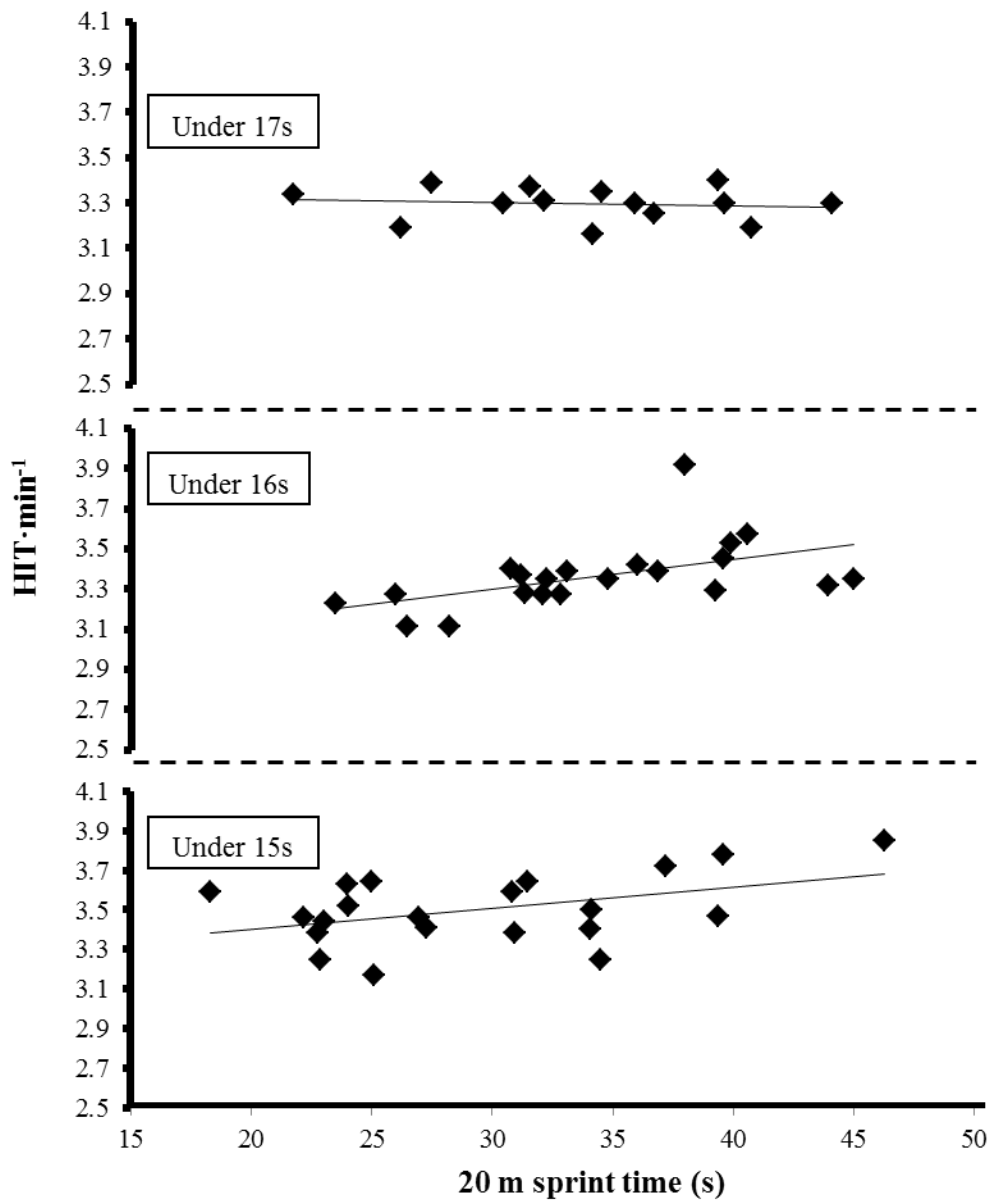


Figure 7.6. The relationship between high intensity running per minute of match time ($HIT \cdot min^{-1}$) and 20 m sprint time for under-15, -16 and -17 players.

There were strong, significant relationships between successful carries and 10 m force in the under-15 group ($R = 0.702$, $P < 0.001$), 16 ($R = 0.607$, $P < 0.001$) and under-17 group ($R = 0.671$, $P < 0.006$) age groups (Figure 7.7). There were further significant relationships between 10 m power and successful carries in the under-15 group ($R = 0.544$, $P < 0.011$), 16 ($R = 0.378$, $P < 0.044$) and 17 ($R = 0.562$, $P < 0.029$).

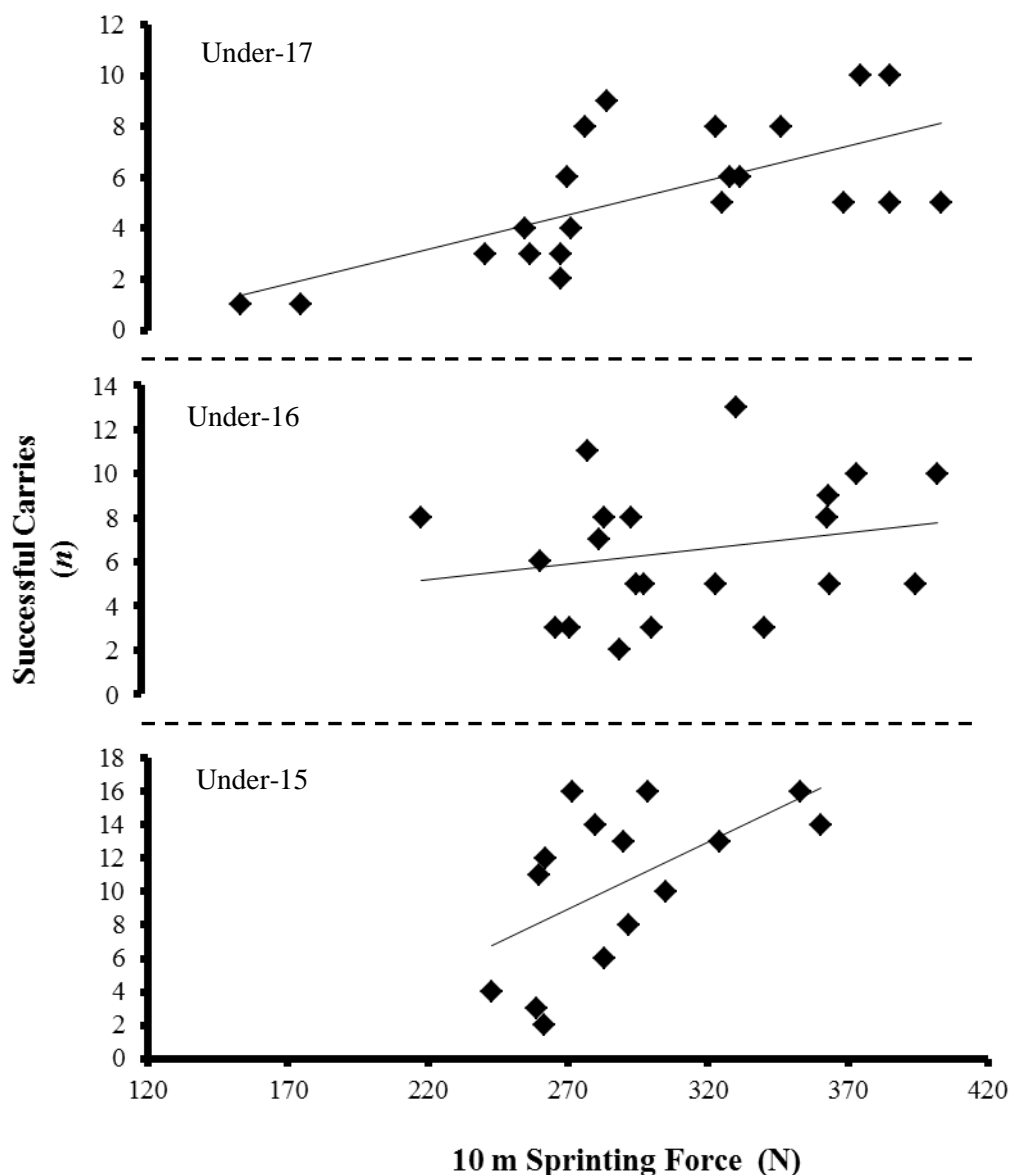


Figure 7.7. The relationship between 10 m sprinting force (N) and successful carries performed in under-15, -16 and -17 players.

7.4 Discussion

One aim of the current study was to identify differences between selected and unselected players based on their average performances during match play. Unexpectedly, none of the match-related performance variables differentiated between these groups among both the under-15 and the under-17 groups. However, within the under-16 age group, the selected players performed for longer match periods compared to unselected players. Given that each of the selected and unselected groups were equally represented by either 'interchange' (two bouts or more) or full-match (single bout) players, there is no clear reason why additional playing minutes were offered to selected players. Fundamentally, selected players in the under-16 group were presented a distinct advantage with regards to match exposure, which is considered to underpin the accumulation of real-world, competitive experience in higher ability athletes (Baker & Horton, 2004). Less exposure to match time may limit the development of players during the 'investment years', where it is assumed that sport-specific skills will be refined and physical fitness qualities can be aligned with the requirements of the sport (Cote et al., 2007). In turn, other time-related factors, such as total distance, HIT distance, Zones 1, 3 and 4 distances, sRPE and summated-HR were also higher in selected players of the under-16 group. The higher physiological 'load' (sRPE and summated-HR) of selected players of the under-16 group, may also provide an additional match-like physiological stimulus with which to adapt to the specific metabolic and mechanical demands of rugby league match play. There were no measures of technical performance that differentiated between selected and unselected players, aside from total and relative successful carries among the under-15 age group. Such findings are likely to relate to the physical superiority of players and advanced maturity of the under-15 age group (also see Chapter 6).

Interestingly, the assessment of performance variables relative to match time (i.e. $\text{m}\cdot\text{min}^{-1}$), highlighted no difference between the selected and unselected groups, suggesting that the intensity (as opposed to duration) of match-running does not differentiate between selected or unselected players at any age group. Such findings are compelling since the playing interval represents the only measured variable that can be controlled by the coaches at the club, who are responsible for selecting players at the end of each season. It is uncertain why such findings occur in the under-16 group but it may be that additional pressure to win competitive matches or to offer ‘favoured’ players competitive match experience before progressing to academy level exists at this stage. The reason this is not seen in the under-17 age group could be a consequence of the amalgamation with older (under-18) players at the Academy, who are often preferentially selected. Nevertheless, such findings raise the question of whether players are preselected based upon their ability to play for prolonged periods at a given intensity or simply afforded greater opportunity in which to develop this facet of match performance. As a result, the markers of match performance measured herein have limited relevance for the identification of young rugby league players when data are normalized to individual match exposure.

When maturational age was introduced as a covariate, unselected players in the under-16 group covered more total and relative distance in zone 4, 5 and HIT. Therefore, the maturity of players moderates the relationship between selection status and match-running performance variables, resulting in the likely de-selection of players who are performing more total and relative HIT running. If factors such as HIT running are regarded as important markers of adult rugby league performance (Sirotic et al., 2009), this is not reflected at younger age groups. Indeed, it would appear that superior running performance is rewarded with de-selection and, therefore, is not a pre-requisite of success during the adolescence

periods herein. Whilst speculative, the ‘compensation phenomenon’ may be considered as an explanation for such results, whereby team sports players of an inferior maturational status are thought to manufacture ways in which to stand-out above their selected peers (Williams & Ericsson, 2005). Conversely, it is also possible that the selected players have developed better decision making capabilities, enabling them to better distribute their high-intensity running throughout the match. However, this is inconsistent with the notion that high intensity running is higher among higher ability players (Sirotic et al., 2009). In any case, the results reject the hypotheses of various qualitative studies in team sports such as soccer (Christensen, 2009; Vrljic & Mallet, 2008), demonstrating that match-running performance does not underpin the coaches’ selection of players. Rather, in agreement with reports in soccer (Malina et al., 2000), the effect of maturity has once again been highlighted as an influential factor in player selection during later adolescent age groups.

In relation to the above findings, it was anticipated that HIT running would differentiate between players of differing ability levels, since this marker of performance is often used to distinguish between players of amateur or elite standards in rugby league (Sirotic et al., 2009). That HIT running failed to identify higher ability players in the current study is interesting since this facet of performance must also be developed (~20%) to meet the standards of adult players (Waldron et al., 2011a). It is likely that these findings relate to the results of Chapter 6 where a later development in aerobic capacity was highlighted, improving by 7% between the under-16 and -17 age groups. Indeed, the relationship between $\text{HIT} \cdot \text{min}^{-1}$ and predicted $\dot{V}\text{O}_{2\text{max}}$ altered from an inverse relationship ($r = -0.460$) in the under-15 group to a positive relationship during the under-17 age group ($r = 0.51$) (Figure 7.5). In a similar fashion, 20 m sprint time began in the under-15 group with a positive (poorer sprint time) relationship ($r = 0.44$), which was later altered to a non-relationship in the under-17

group ($r = -0.07$). These findings suggest that the importance of HIT running may only be used as a useful marker of match performance when more adult-like endurance capabilities are developed. Higher aerobic capacity would help to support the ability of the adolescent athletes to maintain intensities nearer to the supra-maximal threshold (HIT zone demarcation) and recover during intermittent recovery bouts (Singh et al., 2011; Baldari et al., 2004). However, a more detailed understanding of the relationship between $\text{HIT} \cdot \text{min}^{-1}$ and aerobic capacity amongst youth rugby league players is warranted, with emphasis on what training and genetic factors determine its presence. Interestingly, at no stage is faster sprinting performance related to HIT running in adolescent rugby league players. However, the relationship between $\text{HIT} \cdot \text{min}^{-1}$ and 20 m sprint time regressed as a function of age, meaning that poorer sprinting capacity became less associated with $\text{HIT} \cdot \text{min}^{-1}$ among the under-17 group. Such findings indicate a trend for faster sprinters to perform less $\text{HIT} \cdot \text{min}^{-1}$ across age groups but that later developments in aerobic capacity will help to neutralise this relationship. Therefore, rugby league practitioners should not expect aerobic capacity to relate to match running performance until later adolescent years, perhaps placing a later focus on aerobic conditioning. Such strategies would help to align physical fitness qualities of youth players with the increasing demands (longer duration and more contacts) of the game and progressive age groups. As considered below, it is likely that faster, short duration movements correspond to variables beyond match *running* performance.

There was no relationship between technical game actions and sprinting speed in the current analysis, however, 10 m sprinting force (mass x acceleration) related positively to successful carries during every year group (Figure 7.7). These results suggest that the acceleration of the athlete in relation his total body mass provides a better indication of match-related performance than does sprinting speed alone, thus validating 10 m force as a measurement of

rugby league match performance. Force produced over 10 m, as measured in the current study, is likely to relate to successful carries since it would support the athlete in approaching the gain line with greater initial impact, therefore overcoming the advance of the opposing player/s. As such, sprinting force is a physical capacity that best underlies the ability to execute ball carries in rugby league.

Interestingly, tackling did not relate to any features of physical size or capacity, suggesting that the skill of tackling requires more than well-developed physical qualities and may relate better to the application of the appropriate technique amongst adolescent players (Gabbett et al., 2007). In contrast, research in adult rugby league has reported a relationship between the number of tackling attempts and both 10 m ($r = 0.3$) and 40 m ($r = 0.4$) speed (Gabbett et al., 2011c), suggesting a more prominent physical dimension to tackling ability in adult players. However, the moderate relationships found by Gabbett and colleagues suggest that the inclusion of force and power could be a useful future predictor of tackling ability in adult rugby league. Indeed, it has been previously shown that the product of body mass and sprinting velocity (momentum) differentiates between higher and lower division adult rugby league players (Baker & Newton, 2008). Therefore, mass-dependent sprinting variables may provide further value as an indicator of match performance. The relationship of force and power to successful carries during match time supports the value of designing conditioning programmes that cater for these physical and functional qualities. That is, encouraging young adolescent rugby league players to follow programmes that enable the development of acceleration and speed over brief intervals in accordance with gains in propulsive, lean body mass. Other skills that players perform during a match, such as passing and kicking, are often confined to certain positional roles (e.g. hookers and half backs) and, therefore, were not

addressed in the current study. Indeed, it is common that adolescent players will complete a full season without attempting to pass a ball during match time (Waldron et al., 2011b).

Amongst the 12 players who were annually assessed over three seasons, a prominent development in time-related aspects of performance was apparent. In accordance with the ten-minute incremental change in match time at each age group, players increased their total distance in various speed zones between the progressive age groups (Tables 7.8 & 7.9). The change in playing interval also increased summated-HR and sRPE, meaning that the physiological load of players increased as a function of age. Whilst the transition between the under-15 and under-16 groups showed developments in $\text{HIT} \cdot \text{min}^{-1}$ and other relative measurements of running performance, these were decreased between the under-16 group and under-17 group alongside distance in zone 4 and 6 $\text{m} \cdot \text{min}^{-1}$ and $\text{sprint} \cdot \text{min}^{-1}$. In accordance with the macro pacing model of Edwards and Noakes (2009), these changes may be attributed to a lowered distribution of energy resources (lowered intensity) in accordance with increases in match time in order to reach the match endpoint without threatening bodily homeostasis. In other words, the players begin to adopt ways in which to optimise their exertion during match time. The results are indicative of an important year (under-16 to under-17) in the development of adolescent rugby players, whereby the match duration reflects that of an adult context. As such, players are compelled to adapt their playing (pacing) strategy during match time, compromising total match intensity (under-16 group = $90 \text{ m} \cdot \text{min}^{-1}$; under-17 group = $88 \text{ m} \cdot \text{min}^{-1}$) in order to complete the duration required. Such results mirror cross-sectional reports in youth soccer, whereby players in the under-16 group have been shown to perform at lower intensities than under-14 players when annual increases in match duration are enforced (Harley et al., 2010). In the current study, the total intensity ($\text{m} \cdot \text{min}^{-1}$) maintained by players of the under-17 group ($88 \text{ m} \cdot \text{min}^{-1}$) was inferior to adult

players (90 to 95 $\text{m}\cdot\text{min}^{-1}$) (Waldron et al., 2011a; McLellan et al., 2011), demonstrating that further progressions are likely to occur in the following years. The drop in overall intensity can be attributed to the concomitant decline in zones 4 (14.8%) and 6 (50.6%) $\text{m}\cdot\text{min}^{-1}$ between the under-16 and -17 groups (Table 7.8). In accordance, a decline in HR (-0.5%) and perceptual responses (-9.6%) to match play was demonstrated. Concomitant changes in HR values should be expected owing to the down-regulation of movement intensity during the match, resulting in a lowered metabolic signal and a reduced perception of effort (Ratel et al., 2004). Practitioners should remain cognisant of the expected decline in intensity between these age groups owing to the increase in playing interval, and develop training methods that are able to increase total $\text{m}\cdot\text{min}^{-1}$ and higher intensity $\text{m}\cdot\text{min}^{-1}$ ultimately to meet the demands of the adult game. These findings also raise questions over which parameters (i.e. intensity or duration) of match performance should be prioritised during developmental stages in order to produce players that are able to meet the demands of adult rugby league.

Sampling players that completed a full match period over the three seasons revealed a decline in zones 3, 4 and total $\text{m}\cdot\text{min}^{-1}$ between the first and second halves of matches in the under-15 and under-17 groups (Figure 7.1). However, there were no differences between halves for full-match players in the under-16 group or any interchanged players (Figures 7.1 & 7.2). The declines in HIT running (~10 to 20%) were in accordance with first to second half decrements in high intensity running reported in adult rugby league (Sykes et al., 2011; Sirotic et al. 2009). A decline in high intensity running provides an appropriate indication of match-related fatigue in team sports (Mohr et al., 2003). Indeed, decrements in high intensity running have been associated with a deterioration in physical performance of soccer players (such as sprinting and jumping; Mohr et al., 2010) and the presence of peripheral fatigue, such as substrate depletion (Saltin, 1973), hydrogen ion accumulation (Bangsbo et al., 1996)

and potassium imbalance (Krustrup et al., 2006). Whilst the mechanisms of fatigue are unknown in the present study, each of the above factors remains a plausible explanation for the change in high intensity between halves in full-match players. However, as is well understood, team sport performance is self-regulated, permitting transient alterations in match running performance (Mohr et al., 2003). The absence of a decline between halves in the under-16 group may be further evidence of the players' aforementioned developmental period, whereby they are learning how best to accommodate increases in match duration in relation to their physical capacity. This reasoning is, again, consistent with the pacing model of Edwards and Noakes (2009), whereby players of lesser experience are yet to develop an optimal method of energy distribution during match time. This is subsequently reflected by a reservation of match running intensity during earlier periods in order to reach the end-point of the exercise bout in a reasonable physical state. The older under-17 group players appear to show more adult-like match running patterns (see Waldron et al, 2012), even with an increase in match duration.

Interchanged players did not differ significantly across any age group between the first and second halves in match running performance or heart rate responses. In a similar analysis with adult Super League players, Waldron et al. (2012) showed that interchange players' high intensity running declined between the first and second half of a match, owing to an 'all-out' pacing strategy in the first exercise bout. In light of previous research, the current results were unanticipated since interchanged players are typically instructed to make an 'impact' on the match and are given a briefer period in which to do so. Given the similar periods of exercise (~20 min) and recovery separating playing bouts (~25 min) between studies, it may be that the inferior physical capabilities and playing experience of younger players yield a 'flat' pacing profile. These results have relevance for the development of adolescent rugby

league players since certain training modalities, such as maximal repeated sprint programmes may develop anaerobic capacity and recovery between bouts as well as encouraging the adoption of ‘all-out’ pacing in interchanged players (Buchheit et al., 2012a). Greater benefit, both metabolically and mechanically, may be procured from introducing a conditioning programme that closely replicates the repeated sprint efforts experienced during match performance (Spencer et al., 2005).

Between halves of the match, no changes in technical performance (successful and unsuccessful carries or tackles) were evident. Such results are similar to those of Sykes et al. (2011), whereby adult rugby league players demonstrated no change in the number of tackles performed over the course of match, and are likely to relate to the controlled structure of rugby league match play, governed largely by the six tackle turnover, the offside law and the 10 m retreat (RFL, 2011). Whilst players may use the ball (in possession) or approach the opposition (not in possession) in any way selected, rugby league match play follows a relatively predictable rhythmic pattern (Eaves & Evers, 2007). Therefore, it is necessary for players to either take the ball into contact or, conversely, tackle the opposition when doing so. It is well understood that other team sports can be influenced by a variety of factors, including match score, standard of opposition and playing venue (Lago, 2010; Taylor et al., 2010). During soccer matches, for example, Taylor et al. (2010) showed that passing frequency (amongst other variables) was lowered when losing against stronger opposition. Such factors appear less prominent in rugby league and may only manifest themselves in other dimensions of performance aside from tackles and ball carries. It would appear that the signs of match fatigue that have been expressed in running performance are not reflected in the successful or unsuccessful execution of a tackle or ball carry. Such factors, therefore, are not useful measures of match-related fatigue. These findings are contrary to the reports of

Gabbett (2008c) that demonstrated fatigue-induced decrements in tackling technique amongst adult players. However, the results provided in Chapter 5 of the current thesis question the use of simulated tackling tests that evaluate the ‘quality’ of tackling technique in rugby league players. Moreover, self-regulated movement patterns that characterize match-play in rugby league differ from the repeated high intensity running patterns designed to induce fatigue in previous studies (Gabbett, 2008c).

7.5 Conclusion

Players who are selected at the conclusion of each season are not characterized by match-related performance variables. Only as a result of preferential selection and, in turn, greater match exposure during the under-16 age group, do these players perform greater running distances and more successful ball carries. In contrast to adult performances, ostensibly lower ability (unselected) under-15 players perform more high intensity running per minute of playing time when maturational age is introduced as a covariate, but are unrewarded for their efforts. Unselected players are also equally effective in regard to tackling and ball carrying outcomes during match time. In a similar fashion to the results reported in Chapter 6, among the under-17 age group, no match-related performance characteristics differentiated between higher and lower ability players. These results collectively indicate the inability of match-related performance measurements to contribute to talent identification processes in players of this type. Those charged with selecting players for competition should also remain aware of the potential benefits of increased match exposure on physical and cognitive development of young athletes and permit equal match time to all players.

The finding that 10 m force development was significantly related to successful ball carries highlights the importance of both of these characteristics to rugby league match play. These facets of functional performance should be enhanced as a priority through appropriate conditioning practices. During the later under-17 years, improvements in aerobic capacity can be expected in rugby league players which will present stronger relationships with HIT $\text{m}\cdot\text{min}^{-1}$ during this time. Practitioners should be cognisant of the different relationships that certain trained physical abilities have with match performance and adjust their training practices and expectations of players accordingly.

Adolescent rugby league players experienced a development in match running distance in accordance with annual increases in match time. However, after an initial spurt in match running performance relative to time (i.e. $\text{m}\cdot\text{min}^{-1}$ and HIT $\text{m}\cdot\text{min}^{-1}$) between the under-15 and under-16 age groups, the intensity with which they performed stalled at the final transition between the under-16 and under-17 groups. These changes denote an alteration in match intensity to enable the completion of progressively longer matches and should be expected by rugby league practitioners. It should be the aim of coaches and conditioners to develop training methods that are able to increase the total $\text{m}\cdot\text{min}^{-1}$ and higher intensity $\text{m}\cdot\text{min}^{-1}$ of later adolescent players ultimately to meet the demands of the adult game.

Adolescent rugby league players completing a full match demonstrate an inconsistent between-halves performance. This can be attributed to the relative match inexperience of youth players as well as the progressive increase in match time (10 minutes) within each age group. Consequently, the players produce a ‘flatter’ pacing profile throughout the under-16 age group. In particular, interchanged players showed no decline in performance between

halves of the match, which may be attributed to the lack of match experience and inferior physical development compared to adult players. The specialization of interchange type players should begin at the later adolescent stages and prepare players for the brief and more intense match performance that is required in an adult context.

Chapter 8: General Conclusions

8.1 Measuring sprint performance using Global Positioning Systems (GPS)

The validity and reliability of GPS devices for measuring locomotive speed during short sprint intervals is often questioned (Coutts & Duffield, 2010; Duffield et al., 2010). It is preferable to use portable GPS devices to measure sprint performance since concurrent measurements of acceleration and peak speed are also permitted and the GPS device is unaffected by weather conditions or telemetry range. Such issues preclude the use of infra-red timing gates for the same purpose. In the current thesis, concurrently measuring 10 m to 30 m sprint performance using both portable GPS devices and infra-red timing gates has highlighted the underestimation of mean speed and distance when using GPS. These differences are likely to be caused by the relatively low sampling frequency (5 Hz) of the current device (Spi-Pro, GPSports, Canberra), resulting in less positional fixes per unit of movement time. Whilst these findings question the validity of the current 5 Hz GPS model to assess sprint performance, the small degree of total error ($1.1 \text{ km}\cdot\text{h}^{-1}$) found between two repeated sprint trials suggests that potentially meaningful differences between higher and lower ability rugby league players could be detected using relatively small sample sizes of 10 (see Atkinson et al., 1999). Furthermore, the regression model that was developed in Chapter 4 also provided evidence that GPS measurements of sprint performance over 30 m could predict speed measured by infra-red timing gate. Indeed, the use of a regression model that encompasses both mean and peak speed of the GPS was shown to explain 84% of timing gate speed, with sufficient accuracy to discern between ability levels in youth rugby league players (see Gabbett, 2009). Collectively, the results highlighted in Chapter 3 and Chapter 4 demonstrate the consistent underestimation of timing gate speed by GPS devices but confirm the reliability of both methods for the assessment of sprint performance. Importantly, as

reported in Chapter 3, the measurement of peak speed was the most reliable measurement of sprint performance ($CV\% = 0.78$). Conversely, accelerations measured by the in-built accelerometer demonstrated the lowest indices of reliability ($CV = 4.69$ to 5.16%), particularly for the frequency of accelerations > 5 g, where a potential total error of 93% ($95\% \text{ Ratio LoA} = 1.02 \times / \div 1.91$; $CV = 14.12\%$) was observed. This large degree of error found in measurements from the integrated accelerometer indicates the limits of this device for detecting worthwhile changes in performance. These results also raise concern over the use of the accelerometer to detect collisions and decelerating activities during match time, which has been the approach of previous authors studying contact team sports (McLellan et al., 2011; Cunniffe et al., 2009). As such, it was considered that variables generated by the GPS-accelerometer would not be used in Chapter 7, where it was the aim to measure match-related movement characteristics of youth rugby league players.

Given the importance of sprinting performance to rugby league match play (Gabbett et al., 2011a; Waldron et al., 2011a), it was anticipated that assessments of maximal over-ground running would be included over the longitudinal analysis. As such, Chapters 3 and 4 of the current thesis were useful in understanding the limitations of the available measurement methods to assess maximal over-ground speed. It was deemed appropriate to utilize the most reliable variables of sprint performance derived from either timing gate or GPS measurements. In accordance with the findings of Chapters 3 and 4, GPS peak speed and mean timing gate speed were adopted as suitable measurements to be used throughout the three-season period (Chapters 6 and 7). This finding was useful for the choice of certain performance measurements that had not yet been utilized to distinguish between higher and lower ability youth rugby league players. For example, research in rugby league has identified sprint momentum ($\text{mass} \times \text{velocity}$) to discern between higher and lower ability

adult players (Baker & Newton, 2008). Developing upon such findings, Chapter 6 hypothesised that differences in force, as calculated by the rate of peak speed development (acceleration) multiplied by body mass, would associate with players of a higher ability (i.e. selection). As will follow within the current Chapter, measurements of sprinting force emerged as an important discriminator of higher ability.

8.2 Measuring sport-specific skill in rugby league

Successful team sports players are often characterized by superior sport-specific skill (Ali, 2011). This is true for a range of team sports, such as soccer (Huijgen et al., 2010) and rugby union (Pienar et al., 1998). It is also suggested that factors such as tackling proficiency can discern between higher and lower ability players in rugby league (Gabbett et al., 2007). However, in rugby league, tests of sport-specific skill often involve subjective assessments of performance by observers of varying qualification (Gabbett et al., 2010; 2007). Chapter 5 presented the first comprehensive reliability analysis of subjective tests of sport-specific skill in rugby league using the appropriate non-parametric statistical techniques (see Cooper et al., 2007). One should not underestimate the potential to misinterpret the results of such tests if the incorrect statistical process is employed or the qualification of the observer (person judging the test) is disregarded. For example, novice observers tended to overestimate the skills of the youth rugby league players with regard to catching, passing and tackling performance. Furthermore, there were no comparisons between novice and expert observers that met the pre-determined analytical goal of ‘perfect agreement’, for any of the skill components. The same was true for the comparisons between the expert observers, which did not reach perfect agreement, with the lowest values occurring for both tackling skill stages (60% to 65%). Therefore, the current tests of sport-specific skill in rugby league lack the

sensitivity to discern between players of higher and lower ability in the context of talent identification. It was suggested that the credibility of such assessments should be questioned and alternative tests considered. Since the above tests were insufficient in meeting the *a-priori* analytical goals of perfect agreement, their inclusion in Chapters 6 and 7 could not be warranted. Researchers using tests of a similar nature should be cognisant of the issues raised in Chapter 5, especially with regard to tackling performance (poorest agreement between experts: Chapter 5) which is claimed to associate with higher ability (Gabbett et al., 2007). Whilst the exclusion of skill assessments may initially appear to detract from the testing battery included in Chapter 6, later observations revealed a limited occurrence of skills such as passing and off-loading during match time. In many cases, young players will perform for an entire Scholarship season without passing a ball during match time (Waldron et al., 2011b). This observation, alone, should encourage rugby league practitioners to look beyond passing skills for assessment purposes, at least amongst youth players. Of course, it is likely that certain skill assessments have greater relevance for different positional groups. For example, passing during a match is more common amongst half backs and hookers that are often responsible for restarting open play after a 'play the ball'.

8.3 Characteristics associated with selected players

In Chapter 7, the assessment of technical performance indicators during match time showed that successful carries and successful carries per minute were associated with selected players in the under-15 age group. Whilst no other differences (under-16 and under-17 groups) were apparent, the results might indicate that selected players possess this performance characteristic. The reason for the non-significant findings might be related to the larger inter-quartile range of the older age groups and the relatively smaller sample sizes that are

common in case studies of this type. In addition, it is well known that non-parametric hypothesis tests are less sensitive to mean changes owing to their lower power efficiency (Asthana & Bhushan, 2007). Nevertheless, further research is required in order to determine whether the ability to successfully carry the ball during match time is a useful marker of higher ability. Of course, it may be that the frequency of successful ball carrying does not provide a sensitive enough measure to detect successful players and that future research should further investigate successful ball carries in greater detail. This may be supported by developments in integrated micro-electromechanical systems. For example, further knowledge of the kinematic patterns associated with successful ball carrying may support talent development and identification in rugby league. However, the findings of Chapter 3 demonstrated that GPS-accelerometer devices do not provide a sensitive enough measure to determine small (i.e. < 5%) differences in performance. Interestingly, only measurements related to match time, such as total distance covered, differentiated between selected and unselected players in the under-16 group. It was shown in Chapter 7, that selected players of this age group are afforded greater time with which to develop sport-specific conditioning and gather greater match experience. In turn, this may limit the development of players during the ‘investment years’, where it is assumed that sport-specific skills will be refined and physical fitness qualities can be aligned with the requirements of the sport (Cote et al., 2007). There were no other differences between selected and unselected players for any movement characteristic or physiological measurement. In fact, when maturational stage was introduced as a covariate, it was the unselected players that demonstrated superior movement activities, such as total and relative high intensity running. Collectively, these findings suggest that the selection of the coaching staff at the club is not associated with any of the measurements of performance during match time. Therefore, whilst factors such as high

intensity running are considered to be important to adult rugby league players (see Sirotic et al., 2009), this was not the case with Scholarship or Academy players.

In Chapter 6, the force generated over short sprint distances differentiated between selected and unselected players in the under-15 group, independent of maturational age. In the under-15 age group, 30 m force correctly categorized 87.5% of selected players. During the later years, predicted vertical power and squat jump height were higher in selected players, among whom there was a trend for 10 and 30 m force to be higher. It is suggested that these differences are attributable to the demands of rugby league matches, whereby 10 m to 30 m maximal sprinting occurs approximately two-to-three times per minute, some of which involves ball carries and tackles, which occur at a similar rate (see Chapter 7). Indeed, the strong, positive relationship between ball carrying and 10 m force generation was demonstrated at every year group (Chapter 7), thus qualifying the above supposition. Therefore, rugby league practitioners should consider ways in which to develop the linear force generation of players and may use this facet of performance to contribute to the identification of potential talents in rugby league. Given the calculation for force in the current thesis, strategies that focus on developing lean (propulsive) body mass and acceleration over brief intervals would be particularly relevant for the conditioning of rugby league players.

Interestingly, no differences were apparent between the selected or unselected players of the under-17 group during match time or in closed tests of physical performance or anthropometry. Furthermore, the introduction of maturational age as a covariate did not change these conclusions. This is a phenomenon that has been previously raised in research

with junior rugby league players in Australia, whereby tests of aerobic endurance, speed, strength, agility and various anthropometric characteristics could not differentiate between under-18 players that were separated into higher and lower ability categories (Gabbett, 2009). The failure to discern between players during the final stages of adolescence may be due to the progressive filtering of players through the talent development pathway, resulting in more homogenous ability across age groups. Alternatively, the later physical development of some players (see following section 8.4) may result in a belated re-alignment of physical performance between selected and unselected players.

8.4 Longitudinal patterns in physical growth and performance

It was considered important to document the progress of rugby league players over later adolescent years (15 to 18) since the influence of maturity and rate of development has been shown to progressively lessen during this period in team sports players (Philippaerts et al., 2006). Furthermore, rugby league players are likely to be judged on current, rather than potential, performance at later stages. With regard to match performance, an increase in match running distance was demonstrated in accordance with annual increases (10 minutes per year) in match time. This was characterized by an initial acceleration in match running intensity ($\text{m}\cdot\text{min}^{-1}$ and HIT $\text{m}\cdot\text{min}^{-1}$) between under-15 and under-16 groups, followed by a decline in intensity between the under-16 and under-17 groups. Such changes may have been anticipated by rugby league practitioners as players appear to compensate for the progressive increase in match periods by down-regulating their overall exercise intensity. Such findings closely relate to those reported in Chapter 6, whereby a stark rise in force and power development was shown in the first annual transition, which was decelerated in the following transitional period and replaced by improvements in aerobic capacity and muscular

development. Collectively, the current longitudinal evidence shows the physical responses of Scholarship and Academy rugby league players to meet the demands of training and competition. The delay in aerobic endurance development is interesting since this characteristic was strongly associated with $\text{HIT} \cdot \text{min}^{-1}$ among the under-17 players. Whilst $\text{HIT} \cdot \text{min}^{-1}$ did not discriminate selected players in the younger age groups, it appears to be the case at the adult level (Sirotic et al., 2009). This finding is an appropriate example of why the selection of players based upon match running characteristics (such as $\text{HIT} \cdot \text{min}^{-1}$) at earlier ages is erroneous since such factors rely on the physical qualities that do not develop until later years (see Chapter 7). The challenge for rugby league practitioners is to establish the most appropriate methods of developing the factors that best associate with effective match performance at the correct time. It is noteworthy that all of the mean physical performance measurements of Academy under-17 players remained deficient to that of adult populations (see Gabbett, 2002), suggesting an imminent forthcoming period of development both in and out of the competitive environment.

A noteworthy aspect of the current longitudinal analysis was the assessment of first to second half performance profiles in accordance with annual increases in match duration. Adolescent rugby league players completing a full match demonstrated an inconsistent between-half performance. For example, the under-15 and under-17 players tended to decline in various parameters of running performance between halves, whilst the under-16 group did not. The absence of a decline between halves in the under-16 group may be further evidence of a key developmental period for players who are yet to develop suitable aerobic endurance to meet the demands of longer matches. As such, younger players are learning how best to accommodate increases in match duration in relation to their physical capacity. As discussed in Chapter 7, such reasoning is consistent with the macro-pacing model of Edwards and

Noakes (2009), whereby players of lesser experience are yet to develop an optimal way in which to optimally distribute their energy during match time. This is reflected by a ‘flat’ pacing profile between halves of the match. Interchanged players were more consistent, showing no decline in performance between halves of the match, which may again be attributed to the lack of match experience and inferior physical development compared to adult players. As discussed in Chapter 7, the specialization of interchange type players should begin at the later adolescent stages and prepare players for the ‘all-out’ style of performance that has been associated with match performance in the adult game (Waldron et al., 2012).

8.5 Limitations and future recommendations for research

The current study is the first to show longitudinal developments in various aspects of performance both within and out of the match environment in youth rugby league players. Whilst this approach has enabled a detailed appraisal of the current cohort of players, the data presented herein should be considered as preliminary in nature, with future studies focussing upon similar aspects of performance with a broader selection of players. Indeed, it would be useful to cross-validate the proposed selection models presented in Chapter 6 with future players from the same club to assess their general predictive ability.

A useful extension of the current study would be to perform interviews with the selectors/coaches of the rugby league club in order to establish the characteristics that are valued in young players. Whilst previous studies have performed interviews of this type in soccer (Christensen, 2009; Vrljic & Mallett, 2008), there has been no study to directly compare this with an objective analysis of performance, such as that of the present study. Such an investigation might help to realise the relationship between the factors that coaches

ostensibly desire in players and measures of performance and physical growth. Of course, it is possible that such criteria are not 'measurable' factors and remain part of the coaches specialist judgement.

It was the intention of the present study to evaluate the credibility of field-based assessment methods for use in the context of team sport talent identification and development. This was deemed appropriate since assessment methods that can contribute to the talent identification process should be available for use by sport-specific practitioners in the applied environment. Whilst each of the studies show thoroughness to this approach, it is inevitable that such measures lack the control and detail of laboratory-based measurements. For example, maximal aerobic capacity was assessed via the MSFT and was not seen to be different between selected and unselected players over the three-season period. However, as shown by Helgerud et al. (2001), other factors such as running economy may play a more important role with young team sports players (soccer), which were not assessed in the current research. Future researchers may consider developing the sophistication of field-based measurement techniques that can contribute to the talent identification process.

Positional groups, such as backs, forwards and adjustables (King et al., 2009), were not accounted for in the present study. In adult rugby league players, forwards tend to possess more body mass, body fat, and are taller and stronger, whilst backs are often faster and possess higher aerobic capacities (Gabbett, 2002). However, amongst junior players, little difference is apparent between positional groups, with speed, aerobic capacity, muscular power and agility being similar in forwards and backs across under-13 to under-19 age groups (Gabbett, 2002). Whilst not presented in the current thesis, a similar analysis of the

current group of players produced the same results. It is uncertain why differences between positional groups do not occur until later stages (adulthood) but may relate to some of the developmental patterns demonstrated in the current analysis. In addition, both selected and unselected groups comprised an equal distribution of players from the forwards, backs and adjustable positions. It is, therefore, unlikely that there was any influence of positional grouping on the current findings. Future studies, sampling larger groups of players, may wish to explore this topic further.

8.6 Applied implications

This is the first study to report that match-related performance characteristics do not differentiate between elite youth rugby league players who are either selected or unselected by coaches at the end of each season. Rugby league practitioners should be aware that the selection of players based on the match performance variables assessed herein, are unlikely to facilitate identification of higher-ability players. The only exception to such findings appears as a consequence of selected players being given a higher average time on the field of play during the under-16 season. This results in increased total running distances, high-intensity running and the performance of game-related skills. Therefore, rugby league practitioners who are concerned with the selection of youth rugby league players should consider the influence of preferential selection on playing performance. In particular, when selecting players based on their match performance the degree of opportunity should be considered as a confounding factor. In identifying the similarities of relative match performance among selected and unselected players, the current findings make a significant contribution to the search for abilities underlying talented performance in youth rugby league.

A key finding for rugby league practitioners was that 10 m sprinting force was strongly, and consistently, related to $\text{CaS} \cdot \text{min}^{-1}$ among elite youth rugby league players. That acceleration and speed were not related to match performance should signify to rugby league practitioners that interventions aimed at developing speed alone will not affect the match performance of young players. Indeed, the current findings support the value of conditioning programs that develop acceleration and speed over brief intervals in accordance with gains in ‘propulsive’ body mass. Examples of such programs are ‘complex training’ models (mixture of resistance and plyometric training) or power endurance programs, which have been shown to induce changes in anaerobic power and maximal force production alongside increases in muscle CSA and growth-related androgens in youth athletes (Balciunas et al., 2006; Ingle et al., 2006). An important message for applied practitioners is that, whilst the isolated development of aerobic power, speed and CMJ height might be important, they do not support ball-carrying ability among youth rugby league players. Interestingly, practitioners should also be aware that tackling ability did not relate to any of the physical tests that were performed in this study, which is likely to be explained by the higher technical demand of this skill compared to ball-carrying. As such, practitioners should not expect the development of physical size and power to improve tackling skill during matches.

8.7 Continuation of work from the thesis

It is envisaged the current work will be continued by focussing on the mechanisms that underpin the development in physical attributes that have been measured herein. For example, a large development in body mass and predicted muscle mass was identified over later adolescence, which was accompanied by changes in force and power generation. However, the exact training interventions that were responsible for such changes are not yet known. It would be worthwhile knowing whether young rugby league players can enhance

their development of ‘key’ changes in growth and performance by taking part in specific programs, such as the concurrent training models previously discussed. In order to determine the effect of training intervention on match performance, one approach has been to replicate the movement demands of match performance using simulation protocols (Roberts et al., 2010). This approach has been preferred owing to the ‘noise’ present in match running performance (Waldron et al., 2013). Given the vast amount of match performance data that has been collected in the current study it would be useful to replicate the demands of youth rugby league match performance in order to assess the efficacy of training programs among youth rugby league players. Such an approach would also provide an ecologically valid model for the assessment of physical performance, such as sprint ability and match-related fatigue.

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Appendices

APPENDIX 1: ETHICAL APPROVAL

Mark Waldron

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

10 February 2010

Dear Mark

Study title: A longitudinal analysis of performance, growth and maturation in youth rugby league and soccer players: Implications for talent identification and development

FREC reference: 391/10/MW/SES

Version number: 2

Thank you for sending the above-named application to the Faculty of Applied and Health Sciences Research Ethics Committee for review.

The application has been considered on behalf of the Committee by Steve Fallows as Lead Reviewer and reported to the Faculty Research Ethics Committee.

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form and supporting documentation.

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Application Form	2	February 2010
List of references	-	January 2010
Summary CV of applicant	-	January 2010
Participant information sheet	2	February 2010
Consent form	2	February 2010
Risk assessment form	2	February 2010
Letter of permission from RFL	-	February 2010
Response to FREC request for clarification and additional information	1	February 2010

With the Committee's best wishes for the success of this project.

Yours sincerely,



Prof. Cynthia Burek

Chair, Faculty Research Ethics Committee

Enclosures: Standard conditions of approval.

c.c. Supervisor

FREC Representative

APPENDIX 2: PARTICIPANT INFORMATION AND CONSENT FORM

Information Sheet for Participants and Parents/Guardians

Research project title:

“A longitudinal analysis of performance, growth and maturation in youth rugby league and soccer players: Implications for talent identification and development”

Thank you for showing an interest in the above research project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate, we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request. If you are unsure about anything please feel free to contact us using the details provided in the following sections.

What is the purpose of the study?

This study is being undertaken as part of an original postgraduate research project (PhD) in Sport and Exercise Science. The purpose of this project is to find out how ‘you’, an elite rugby league or soccer player, develops physically and performs both in training and matches during the three-year period leading to adult transitions (under-15 group to under-17 group). We will be looking specifically at changes in your maturity, growth, physical performance, skills that you perform throughout a competitive match, how you move around the pitch and how your heart rate responds to this during competitive matches. This will include, for example, the amount of successful passes, shots, tackles you perform and distance and speed travelled. One advantage of knowing this information is that it can be later used by your coaches to prepare you for competition. It will also enable us to gather an idea of what it takes to be an elite youth team sports player. This project will be the first of its kind in Britain and is viewed as an excellent opportunity for all potential participants.

Why am I being invited to take part?

As an elite youth male soccer or rugby league player, competing at the under-15 group, the ways in which you perform during match time is key to understanding what it takes to maintain your elite status. We see this as an opportunity for us to develop an understanding of this, with the eventual aim of improving the performance of young players.

Do I have to take part?

No, you do not have to take part in this project. Indeed, declining our offer or withdrawing from this project will not affect your performance or health in any way. You will not have to give a reason for choosing not to participate. If you decide to take part, you will keep this information sheet and be asked to sign the consent form (see following sections).

What will happen to me if I take part?

You will take part in annual (each year) assessments of body size and shape, which will include measurements of your height, weight, leg and arm length, body composition (Body fat%) as well as measurements of physical performance. These will consist of the multi-stage fitness test (or the ‘bleep test’), maximal jumping performance, maximal sprinting performance and tests for sport-specific skill. This study will also encourage you to perform within your natural sporting environment. All you will have to do is to play under normal match or training conditions. During this time, you may be recorded by one or more cameras situated at pitch side. In total, you may be filmed and analyzed for an entire season of matches with your club. Your only responsibility is to turn up and play wearing the suitable equipment. This will enable an analysis of technical skills that you will be performing, such as short passing, crossing, tackling (for example). In order to gather a greater understanding of your movement around the pitch and the response of your body to this, you will be fitted with global positioning satellite technology (GPS) and heart rate (HR) monitors. These can be seen in the pictures below (figure 1 and 2 show GPS; figure 3 show heart rate monitors). As you move around the pitch the GPS monitor will receive a signal from a satellite and pinpoint your exact position throughout the match. At the same time, the beating of your heart will be recorded by the heart rate monitor.



Figure 1. GPS harness/vest



Figure 2. GPS monitor

(GPS monitors fitted in a protective pouch as pictured in figure 1)



Figure 3. Heart rate monitor (chest strap)

Recording this information will enable you and your coaches the opportunity to understand your average heart rate throughout the match and how fast you move around the pitch. As a result, we may then develop training methods to suit these outcomes.

After the training or match event has finished you will also be asked for your rating of perceived exertion (RPE). This is a simple measure aimed at finding your opinion of how hard you have worked during the session/match. There are no 'right' or 'wrong' answers for this measure as this is individual to each player. This will take less than 30 seconds to complete. You will be given further instruction of this prior to the commencement of the study.

What are the disadvantages and risks?

Every measure has been taken to ensure safe participation in this study. The risks involved are the same as you would take within any sports contest.

What are the benefits?

Feedback of the results from this study during the season will be at the team manager's discretion, who has agreed to this study taking place and view this as an aid to effective coaching. We would hope that knowing how hard you are required to work and what skills you are required to perform during competitive matches will better prepare you for what you are about to face as a young football player, developing you for future years.

What use will be made of the results?

The bodily measurements, physical performance results, video footage and GPS profiles gathered from matches will later be used by the researcher in order to analyse the performance of all players. All data will be used for this sole purpose with access granted only to those researching this study and who are CRB approved.

Results of this project may be published in the future but any data included will in no way be linked to any specific participant, with ***complete anonymity and confidentiality guaranteed.***

You are most welcome to request a copy of the results of the project should you wish. Indeed, the club involved in the project will also receive a copy of all results in order to inform the development of the young players.

The data collected will be securely stored in such a way that only those mentioned above will be able to gain access to it. All raw data on which the results of the project depend will be retained in secure storage for 10 years, after which it will be destroyed.

What if something goes wrong?

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Professor Sarah Andrew, Dean of the Faculty of Applied and Health Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, United Kingdom, 01244 513055. If you are harmed by taking part in this research project, there are no special compensation arrangements. If you are harmed due to someone's negligence (but not otherwise), then you may have grounds for legal action, but you may have to pay for this.

What if Participants have any Questions?

If you have any questions about our project, either now or in the future, please feel free to contact:-

Mark Waldron (BSc; MSc)

Postgraduate Researcher

Department of Sports and Exercise Sciences,

University of Chester,

Parkgate Road,

Chester,

CH1 4BJ

Telephone: [REDACTED]

Mobile Telephone: [REDACTED]

Email: m.waldron@chester.ac.uk

Consent form for Participants and Parent/guardian

Research Project Title:

“A longitudinal analysis of performance, growth and maturation in youth rugby league and soccer players: Implications for talent identification and development”

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

1. My participation in the project is entirely voluntary.

2. I am free to withdraw from the project at any time without any disadvantage.
3. The data will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for ten years, after which it will be destroyed.
4. If at any time I feel discomfort or risk due to the project, I am free to withdraw.
5. The results of the project may be published but my anonymity will be preserved.

I agree to take part in this project.

..... (Signature of participant)

..... (Date)

..... (Signature of parent/guardian)

..... (Date)

APPENDIX 3: LETTER OF APPROVAL FROM THE RUGBY FOOTBALL LEAGUE



Ref: CB

22 April 2010

Mr M. Waldron
Department of Sport and Exercise Sciences,
University of Chester,
Parkgate Road,
Chester,
CH1 4BJ

Dear Mr Waldron

Red Hall
Red Hall Lane
Leeds
LS17 8NB

Tel: 0844 477 7113
Fax: 0844 477 0013
Email: info@rfl.uk.com

www.rfl.uk.com

GLOBAL POSITIONING SATELLITE UNITS

We authorise Mark Waldron and associated colleagues from The University of Chester to use fitted vests and Global Positioning Satellite (GPS) units (GPSports, SPI Elite, Australia) and heart rate monitors (T31 transmitter belts from Polar Electro, Oy, Finland – please note the newer Polar designs with detachable transmitters are not authorised) with players contracted to St Helens Rugby League Football Club, inclusive of all youth age groups from under 15's through to under 18's. All players and parents involved must receive informed consent of the project and all data will conform to current rules and regulations regarding confidentiality and anonymity of players.

Whilst we support the research, it needs to be recognised that St Helens need to be satisfied that the unit carried by each player, like all pieces of kit and equipment used, does not endanger the health and safety of the player or his team mates/opponents. I present this concern as players of this age are not of a similar stature / body shape (especially around the upper back where the unit is housed) to the senior professionals who have used this equipment previously. If St Helens are in doubt about whether the unit will endanger the health and safety of the individual player or his team mates/ opponents, they should seek the advice of the match officials or match commissioner to resolve the issue and ensure the unit does not present a danger to participants.

For use of this data in an academic research project, the data should be kept confidential from any other individuals apart from those involved in current analysis projects at the University of Chester. Anonymity of the players should be maintained throughout the project, protecting personal identities. Upon completion of the study, all data should be kept as part of an ongoing applied sport science support commitment at the department of Sports and Exercise Sciences (University of Chester). As discussed, we would also request that the data is shared with the RFL as part of wider ongoing research into game demand and player development.

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APPENDIX 4: OPERATIONAL DEFINITIONS FOR ALL PERFORMANCE INDICATORS

Successful Tackle: A successful tackle occurs if the opposition player in possession of the ball comes in to contact with and is held by a player under analysis, resulting in the player in possession being unable to make any further progress. The ball may be dislodged during this time and the player in contact may often be propelled to the floor.

Unsuccessful Tackle: When a defending player (under analysis) is deemed to have attempted to make a tackle on an attacking player by making visible and physical contact but fails to execute the actions that constitute a successful tackle. These may be that; the attacking player in possession offloads the ball; the attacking player advances whilst the tackle attempt is on-going; the attacking player in possession scores try; the defending players commits a foul during the process of the tackle.

Successful Carry: When a player in possession of the ball moves to an advanced pitch position that is deemed to be closer to the opponents' try line from where the player originally received possession of the ball, without turning over possession or being propelled backwards by the tackler.

Unsuccessful Carry: When a player in possession of the ball fails to move to an advanced pitch position that is deemed to be closer to the opponents' try line from where the player originally received possession of the ball, which may result in that player turning over possession or being propelled backwards by the tackler.

APPENDIX 5: RAW SPSS DATA FILES

As arranged on the disc supplied